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IITRI Report C06538-2
TOTAL SYSTEM HAZARDS ANALYSIS FOR THE WESTERN AREA
DEMILITARIZATION FACILITY AT HAWTHORNE ARMY AMMUNITION PLANT
PRIORITY 2 - PREPARATION BUILDING, ACCUMULATOR,
MECHANICAL REMOVAL BUILDING AND LARGE CELLS
Volume 1, Summary Report and Appendices

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November, 1982

FOREWORD

This is the second of three reports to be submitted under Contract No. DAAA09-51-C-3006 being conducted by IIT Research Institute, Chicago, Illinois, for the U. S. Army ARRCOM, Rock Island, Illinois. This report describes the results of a hazards analysis of the Preparation Building, Accumulator, Mechanical Removal Building, and Large Cells (Priority 2) at the Western Area Demilitarization Facility (WADF) at Hawthorne, Nevada. A hazards analysis report was submitted during July 1982 for the Steam and Hydraulic Systems at WADF. The hazards analysis for the Priority 3 systems (the decontamination and small items building, the flashing chamber, the driverless tractor system and the off loading dock) is to be submitted at a later date. The Priority 2 Report is submitted in two volumes, Volume 2 containing fault tree diagrams for the systems evaluated. The primary IIT Research Institute project team consisted of Ronald Pape, Edmund Swider, Kim Mniszewski, Charles Heilker, Dwayne Eacret, and Cindy Marrazzo. Mr. Thomas Grady, a private consultant with considerable experience in explosive and propellant operations, helped scrutinize the results of the analysis.

Respectfully submitted
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1. INTRODUCTION

This report contains the results of a hazards analysis of the Preparation Building, Accumulator, Mechanical Removal Building, and Large Cells at the Western Area Demilitarization Facility (WADF) at Hawthorne, Nevada. The methodology used was a combination of failure modes and effects analysis (FMEA) and fault tree analysis (FTA), with quantification accomplished through the use of a fault tree computer model. These techniques were described in the Priority 1 report and are repeated here in Appendix A.

The hazards analysis that was conducted produced two types of results. First, the scenarios that can lead to a hazardous outcome were identified by constructing fault tree logic diagrams for each plant section. Such scenarios are chains of events or combinations of events that must occur together or in sequence to cause the outcome of concern. For example, for an operator to become burned by touching a hot surface, several things must happen:

1. the surface must be sufficiently hot to burn someone, and
2. an operator must touch the hot surface

Both of these events are necessary in order for the operator to become burned. The combination of events is a scenario. To evaluate whether such a scenario is significant, "probability of occurrence" values are derived for each event in the scenario, thereby making it possible to compute the overall scenario probability of occurrence. Scenario probabilities are derived in terms of probability per year, or expected frequency of occurrence averaged over an extremely long time frame.

All the scenarios for the specific plant section are then compared based on their derived probabilities per year. Naturally, those scenarios with the highest probability values are most critical and must be addressed first.

Section 2 of this report summarizes the systems at the Western Area Demilitarization Facility that have been evaluated under Priority 2. Section 3 presents the hazards analysis results for each plant area. Section 4 provides recommendations and conclusions based on the results of this analysis. In

addition to a discussion of the hazards analysis methodology in Appendix A, the appendices provide more detailed information on the preparation building ether vapor problem (Appendix B), initiation probability curves constructed for propellants (Appendix C), transient heat transfer models used for the required engineering analyses (Appendix D), and a model to estimate the maximum electrostatic discharge energy for a dielectric surface (Appendix E).

2. PRIORITY 2 SYSTEMS

The systems at WADF evaluated for potential hazards under Priority 2 include the Preparation Building, Accumulator System, Mechanical Removal Building and Large Cells. These systems are described briefly in this section.

2.1 PREPARATION BUILDING AND ACCUMULATOR

Mechanical disassembly of items is to be performed in the Preparation Building in individual cell areas of the building. Processes include (1) pull apart of elements joined by crimping (e.g., removing the projectile from the cartridge case); (2) unscrewing the parts such as fuzes from projectiles, rocket motors from warheads, or fuzes and fin assemblies from mortar cartridges; (3) removal of propellant from cartridges; and (4) removal of primers from cartridge cases. The Preparation Building cells are to handle gun type ammunition up to and including 6 inch. There are six work cells in the building. Each cell has 4 UV detectors and a preprimed (wet) water deluge system. Operations are monitored by closed circuit TV. Currently cells 1 and 2 are not equipped.

Cell 3 is currently for breakdown of 60 mm and 81 mm mortar cartridges. Two rounds at a time are placed on a holding fixture (steel plate shuttle) in front of the cell by an operator. At the proper time, the holding fixture is indexed into the cell through an access port. Once inside the cell, under the watchful eyes of the control operator, the previously disassembled two rounds are picked up by the robot (manipulator) at the disassembly "lathe" and placed in the holding fixture. Next the robot picks up the complete rounds and brings them into clamping position at the "lathe". With the rounds held firmly, the chucks on either side of the cartridge unscrew the fuze on one end and the tail fin on the other end. The head and tail units are then automatically picked up and dropped into water filled containers sitting next to the machine. The mortar body is carried by the manipulator to the shuttle conveyor to the corridor outside the cell.

Cells 4, 5, and 6 are dedicated to disassembly of gun ammunition. A conveyor from the corridor carries projectiles and cartridge cases into Cell 5.

In Cell 5, a pull apart machine removes the projectile from the cartridge case on fixed munition. For plugged cartridge cases, when the shell and case are separate (separate gun ammunition) the pull apart machine is replaced by an end cut off machine which removes the end of the case by using a tube cutter type device. In that case, the projectile enters Cell 5 separately and goes directly to Cell 6. In Cell 6, an unscrewing machine, just like that in Cell 3, is used to remove fuzes and base fuzes.

The cartridge cases are moved by the robot from the tube cutting device into a horizontal position for the removal of a wad prior to dumping of the propellant. The propellant is dumped from the cases onto a conductive rubber belt conveyor to be carried to the accumulator building. Then the cartridge case is shuttled into Cell 4 via a conveyor. In Cell 4, the cartridge case is automatically placed into a fixture to punch out the primer in its base. When the cartridge case is conveyed back into the corridor, the operator must manually remove the primer from the inside of the case.

As mentioned above, the propellant removed from the cartridge cases is conveyed to the Accumulator Building. The conveyor is enclosed and protected with UV sensors, and deluge nozzles every six feet. At the accumulator, the receiving storage hopper is equipped with two high-level sensors, the lower one to stop operations in Cell 5 of the preparation building and the upper one to stop the conveyor motion. The material is routed from the storage hopper to a vibratory feeder conveyor and finally to a weigh hopper. The propellant is then metered into type III or MK IV containers for storage or sale. Two bag collector units service the preparation and accumulator buildings. In addition, a vacuum system is available for special cleanup operations. Four vacuum cleaning units each consist of a cyclone separator, wet collector and dry collector. These are housed in the cells immediately adjacent to the central propellant packaging cell. The outermost cells hold the pumps used to pull the air through the vacuum collection units.

2.2 MECHANICAL REMOVAL BUILDING

The mechanical removal building contains equipment used to expose the interior of conventional munition items and to provide access for explosive removal processes. Also, in some cases on large munitions, the facility

is used to provide vent/view holes in the item to facilitate inspection of the items prior to flashing them of residual materials in the flashing chamber. The operations include trepanning (hole cutting), sawing, shearing and punching of holes in munition items. Before entering the mechanical removal building, some items are washed/steamed out leaving only small amounts (under ten pounds) of explosive in them, with acceptance determined by visual inspection, while other items are fully loaded.

Forklifts are used to move items from the conveying vehicle (driverless tractor and carts) into the building where jib cranes are employed at the corridor-to-cell port of each cell. On all large or heavy items jib cranes are used to place items onto carriages/tooling which convey the items into cells for processing on"through-port" conveyors.

All operations in the cells are controlled remotely by operators in the control room of the building. Cell 1 houses equipment used for punching holes in, or shearing, relatively small munition items (such as MK1 boosters or MK42 primers) containing appreciable amounts of energetic material. Ammunition items are mounted on tooling carrier plates that ride on a conveyor. Clamping elements hold the tooling carriers in a predetermined position in the press accurately and positively for shearing and/or punching. Presently primers longer than 8 inches are to be sheared into smaller pieces using an industrial-type hydraulically operated press.

Cell 2 contains a band saw for sawing items 25 inches in diameter or less. Presently the MK 4 depth charge noses are to be sawed off by the band saw to expose the explosive charge for easier removal. The items are clamped to a tooling carrier which rides on a conveyor between the band saw and the corridor. A powered-roller conveyor is used together with a ball transfer table to manipulate the tooling carriers. Holding clamps fix the tooling carrier accurately and positively in a predetermined position while sawing is underway.

Cell 3 holds trepanning (hole sawing) equipment to cut a series of 5 inch diameter vent/view holes simultaneously in large munition items. A special

hole cutting machine, equipped with a shuttling carriage, a deep bed filter and an aspirator is applied in Cell 3 to produce the vent/view holes. The shuttling carriage rides on two-section ways, one section inside the cell and the second section in the corridor. The hole cutting machine consists of a framework on which six horizontally oriented, hydraulically powered spindle heads are mounted in parallel. A hydraulic cylinder on each head provides the stroke. A "slug" ejection device is provided on each head to push the cut-out portion of the items out of the hole saw and into the item being processed. In conjunction with the heads are six horizontally oriented, hydraulically actuated backstop units provided. The purpose of the backstop units is to resist the force applied by the heads during the cutting operation.

An aspirator is included as part of the hole cutting equipment to remove the coolant accumulated in the interior of the item during hole sawing. Coolant is removed from the item when it is returned to the corridor. In special cases should additional vent area be required or should view openings in other places be required, after the first array of holes are cut and the item retracted to the corridor, the clamps holding the item can be released, the item rotated on the carriage, reclamped, and reintroduced to the cell for the cutting of another set of holes in a second plane.

At the time of the hazards analysis the major cells were operational and equipped with the appropriate machines, conveyors, tooling/fixtures, and jib cranes or assist devices. Two smaller cells and an extra room are located in the Mechanical Removal Building on the same side of the corridor as the operational cells. Across the corridor from the cells is the mechanical room housing all equipment and utilities necessary for the operation of the building. Also, the control room is located across from the cells, housing the controls necessary to remotely operate the equipment in the cells together with CCTVs* to observe the operation in each cell.

2.3 LARGE CELLS

Three large cells (constructed with frangible walls and ceilings due to the hazardous operations performed on large munitions) are located adjacent to the mechanical removal building. These house machines used in disassembly operations for

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*Closed Circuit Televisions

large munitions items. Two of these cells are currently in use. Cell B is set up for cutting open MK 16 mines using a band saw. Cell C contains an unscrew machine for defuzing major caliber munition items. Cell A is presently empty and could be used for temporary storage (within allowable charge weight envelopes) of large munition items. These cells are serviced by an over-head bridge crane system to move the large munition items in and out of the cells.

3. SUMMARY OF HAZARDS ANALYSIS RESULTS

3.1 PREPARATION BUILDING

Results of the fault tree analysis of the Preparation Building operations indicate a category I or II accident frequency of 0.402 per year, excluding injuries and illnesses of various causes. Of these 0.402 incidents per year, 0.327 per year were equipment damage mainly due to machinery impacts and robot malfunctions. Explosive and propellant fires made up the remaining 7.51×10^{-2} incidents per year.

The accident frequencies are further categorized in Table 1, for the seven areas in the preparation building where explosive items are handled, including:

- Offloading Areas
- Cell 1 (unsafe item storage)
- Cell 3 (mortar shell disassembly)
- Cell 4 (deprimer operations)
- Cell 5 (pull-apart, case cutter, case dumpers and item transfer operations)

In order to quantify the fault tree analysis, scheduling data was required. Since long term production rates for each area and for each type of projectile are not firm at this time, estimates* had to be used. The values that were used are summarized below:

- nominal production rates are 89/hr for the Cell 3 operations (mortar shell breakdown) as well as the Cell 4-5-6 operation (gun ammunition breakdown)
- both of these operations are assumed to be run simultaneously
- operations will take place during two shifts per day (16 hours)
- For Cell 5 pull-apart and case cutter operations, the processing rates are weighted by the amount of different item categories requiring these facilities (i.e. 18 items per hour in the pull-apart operation and 71 items per hour in the case cutter).

The most serious incidents considered are those involving explosion and fire because of the high potential human and property losses. The fault tree

*These estimates are based on considerable analyses presented in reference 2.

Table 1 Estimated Accident Frequencies in Preparation Building Areas (per year)

Area	Frequency of Category I or II Accident		Frequency of Explosion/Fire	Frequency of Other Major Equipment Damage
Offloading Area	8.88×10^{-4}	ok	8.49×10^{-4}	3.90×10^{-5}
Cell 1	6.19×10^{-6}	ok	6.19×10^{-6}	--
Cell 3	6.55×10^{-2}	ok	2.32×10^{-2}	4.23×10^{-2}
Cell 4	9.14×10^{-2}	ok	1.65×10^{-3}	8.97×10^{-2}
Cell 5	9.01×10^{-2}	ok	1.59×10^{-2}	7.42×10^{-2}
Cell 6	8.99×10^{-2}	ok	2.59×10^{-2}	6.40×10^{-2}
TOTAL	0.402		7.51×10^{-2}	0.327
	.338		6.6×10^{-2}	.270
			$\sim 1 \times 10^{-2}$/year	

analysis has shown the most probable scenarios are those involving manual item handling operations, fuze drop-tank problems, manipulator malfunctions, pull-apart/case-cutter ether problems, station/station transfer machine problems, external contamination problems, driverless tractor operations, and particular ESD problems. The most significant of these are described below for each cell in the preparation building

3.1.1 Offloading Area

The offloading area is the receiving area for the Preparation Building. The expected accident frequency in this area is less than that estimated in the distribution area where much more manual handling of single items is done. Accident scenarios with the highest frequency of occurrence in the offloading area resulted from the following:

- Driverless tractor impacts a wall or fixed object (8.47×10^{-4}/year) OK
- Impact initiation during maintenance in which heavy equipment is moved, (3.9×10^{-5}/year) OK

Driverless Tractor Impacts a Wall or Fixed Object (8.47×10^{-4}/year)

In this scenario, a driverless tractor cart load impacts a wall or fixed object while the items to be processed are brought into the preparation building.

This scenario is summarized in the table below.

Fault Tree Component No.*	Description	Probability/ Frequency Used
24	driverless tractor load arrives at off-loading area	1.85/hr
25	during transfer operation, operator backs cart into wall or fixed object (human error probability)	0.01
26	Impact is sufficient to cause initiation of items**	1.1×10^{-5}

* Component numbers correspond to the fault tree numbering that appears in Volume 2.

** The value of 1.1×10^{-5} for rough handling of full munitions items is discussed in the Priority 1 report.

Impact Initiation During Maintenance in Which Heavy Equipment is Moved
(3.9×10^{-5}/year)

In this category of scenarios, maintenance is required in the offloading area in which heavy equipment must be moved. Due to a human error the equipment being moved experiences an impact causing major damage.

This scenario is summarized below.

Fault Tree Component No.	Description	Probability/ Frequency Used
74	Heavy equipment is moved during maintenance	3.125×10^{-3}/hr
75	Operator error during transfer causes impact	0.003
77	Impact is sufficient for major equipment damage	0.001*

* Based on engineering judgement

3.1.2 Cell 1

Cell 1 in the preparation building is to be used for intermediate storage of "unsafe" items. The items are stored until enough of them accumulate to be taken away to the disposal area. "Unsafe" items here are any items which appear to be unfit for processing or those which do not make it through complete processing (e.g. jammed items). It is judged that one out of every thousand items may be categorized as unsafe, from discussions with ARRCOM personnel.

Accident scenarios with the highest frequency of occurrence here include:

- Item/Package Dropped by Operator During Transfer Causing Initiation (1.19×10^{-6}/year) OK
- Explosive Contamination is Initiated by a Dropped Tool or Other Item (5.0×10^{-6}/year) OK

Item/Package Dropped By Operator During Transfer Causing Initiation (1.19×10^{-6}/year)

OK should be 1.19×10^{-5}

While transferring "unsafe" items to or from Cell 1, an operator error could result in an item or package of items being dropped. There is a probability that such a drop will result in initiation of an item. This is particularly hazardous since the operator is present and could be seriously injured.

This scenario is summarized below.

Fault Tree Component No.	Description	Probability/ Frequency Used
43	Item or package dropped by operator during transfer operation*	2.6×10^{-4}/hr
2	Drop impact is sufficient for initiation**	1.1×10^{-5}

* Frequency of transfer operations times the probability of a human error resulting in the item or package being dropped

** Items impact probability value discussed in the Priority 1 report.

Explosive Contamination is Initiated by a Dropped Tool or Other Item (5.0×10^{-6}/year)

OK and checked

With poor housekeeping, explosive contamination could accumulate in the area. If a tool or other object is dropped onto such a thin layer of explosive, an initiation could occur. The operator dropping the tool or other object could be seriously injured if the contamination layer flashes. If the "unsafe" explosive items are initiated, Cell 1 could sustain significant damage.

This scenario is summarized below.

Fault Tree Component No.	Description	Probability/ Frequency Used
9	Area is not cleaned frequently enough (human error)	0.001
10	Explosive particles collect on surfaces (this will happen if component 9 occurs)	1.0
11	<u>Significant</u> layers build up over time	0.5
12	Tool or item drops on layer; initiation occurs*	2.4×10^{-4}/hr
34	Deluge system activated too late to prevent propagation	0.02
3	Propagation to unsafe explosives**	0.5

* Frequency of large tool drops times probability of initiation

** Engineering estimate

3.1.3 Cell 2

No activities are currently planned for Cell 2, therefore, a hazards analysis was not required for this area.

3.1.4 Cell 3

Cell 3 is the mortar shell disassembly operation. As indicated in Table 1, Cell 3 has a fairly high estimated frequency of an explosion occurring (i.e. 2.83×10^{-2}/year). This high frequency of explosion accidents is mainly due to the scenarios listed below:

- Impact Initiation Resulting from the Water Filled Fuze Drop Tank Being Overfilled with Fuzes or Not Filled with Water (2.2×10^{-2}/year) Not OK
- Fuze Safety Wire Pulled Out by Cell 3 Machinery Prior to Drop into Fuze Drop Tank which has too many Fuzes or Too Little Water (4.63×10^{-4}/year) OK
- Impact Due to Mechanical Failure of Manipulator Gripper (4.1×10^{-4}/year) OK
- Operator drops item while loading/unloading (4.07×10^{-4}/year) OK

Separate scenarios were also identified which do not involve explosion, but can result in significant equipment damage anyway.

- jib crane operator human error during maintenance causes equipment damage (1.56 X 10^{-3}/year)
- manipulator mechanical failure during transfer operations causes major impact; equipment damaged (3.70 X 10^{-3}/year)

A better estimate of accidents due to manipulator failures can be made if better failure rate data can be found for this equipment. Generic failure rate data has been used in the above estimates.

<u>Impact Initiation Resulting from the Water Filled Fuze Drop Tank Being Overfilled with Fuzes or Not Filled with Water (2.2 X 10^{-2}/year)</u> = 2.2 x 10^{-3}

The water filled fuze drop tanks are required in the system to cushion the impacts when fuzes are collected in the Cell 3 disassembly operation. If the tank is not filled with water or if the tank is allowed to become overfilled with fuzes, the water's protective cushion would be eliminated and impact initiation of the fuzes would become possible. 4.07 x 10^{-3}

A typical scenario in this category is summarized below:

Fault Tree Component No.	Description	Probability/ Frequency Used
141	Fuze released from fingers	178/hr
145	Water tank overfilled with fuzes (human error)	.001
142	Fuze impacts	1.0
143	Impact is sufficient for initiation*	1.1 X 10^{-5}
144	Explosion propagates to other fuzes**	0.5

* Item impact probability discussed in Priority 1 report

** Engineering estimate

<u>Fuze Safety Wire Pulled Out By Cell 3 Machinery Prior to Drop Into Fuze Drop Tank Which Has Too Many Fuzes or Too Little Water (4.63 X 10^{-4}/year)</u>

The previous scenario, in which the fuze drop tank is allowed to become overfilled with fuzes or not filled with water, will be more severe if

the fuze safety wire is pulled out during the unscrewing operation. The wire could be pulled out if the head chuck is out of adjustment and extends out over the wire. A typical scenario in this category is summarized below.

Fault Tree Component No.	Description	Probability/ Frequency Used
145	Water tank overfilled with fuzes (human error)	0.001
270	Item is processed	89/hr
271	Fuze is released by fingers	1.0
272	Fuze impacts	0.5
273	Sufficient impact for initiation (estimate without safety wire)	0.5
274	Propagation to other fuzes (engineering estimate)	0.5
275	Head chuck extends to wrong position over safety wire (out of adjustment)	1×10^{-5}
276	Head chuck is clamped	1.0

Impact Due to Mechanical Failure of Manipulator Gripper (4.1×10^{-4}/year)

If a manipulator in Cell 3 fails mechanically it could cause an item to sustain an impact during transfer. Such an impact could result in the initiation of the item. This scenario is outlined in the following table:

Fault Tree Component No.	Description	Probability/ Frequency Used
77	Item being handled by manipulator	89/hr
78	Mechanical failure occurs, causing impact of item against equipment	1×10^{-4}
79	Impact sufficient for initiation*	1.1×10^{-5}

* Impact initiation probability discussed in Priority 1 report

Operator Drops Items While Loading/Unloading (4.07×10^{-4}/year)

The items processed in Cell 3 must be manually loaded onto the shuttle conveyor leading into the cell. This provides the opportunity for the operator loading the items to drop one:

Fault Tree Component No.	Description	Probability/ Frequency Used
30	Operator drops item during loading/unloading operation	8.9×10^{-3}/hr
6	Drop is sufficient for initiation*	1.1×10^{-5}

* Item initiation probability discussed in Priority 1 report

Mechanical Damage Scenarios Not Involving Explosion (4.23×10^{-2}/year)

The three major categories of non-explosion scenarios resulting in significant equipment damage are summarized on the tables given below:

Equipment Damage Due to Manipulator Mechanical Failure (3.702×10^{-2}/year)

Fault Tree Component No.	Description	Probability/ Frequency Used
77	Item being handled	1 = 89/hr
78	Manipulator mechanical failure, causing impact of item against equipment	1×10^{-4}
80	Impact sufficient for equipment damage (based on engineering judgement)	0.001

Equipment Damage Due to Jib Crane Operator Error (1.45×10^{-3}/year)

Fault Tree Component No.	Description	Probability/ Frequency Used
216	Jib crane used during maintenance	1.25×10^{-3}/hr
217	Heavy items lifted	1.0
221	Operator control failure causes item drop (human error)	0.003
218	Equipment damaged (engineering estimate)	0.1

Equipment Damage due to Manipulator Computer/Electronic Failure (3.702×10^{-3})

Fault Tree Component No.	Description	Probability/ Frequency Used
67	Item being handled	89 /hr
68	Manipulator computer/electronics failure, causing impact of items against equipment	1×10^{-5}
70	Impact is sufficient for equipment damage (engineering estimate)	0.001

3.1.5 Cell 4

Cell 4 is the depriming operation where primer tubes are punched out of empty cartridge cases. The estimated frequency of fire/explosion accidents are mainly due to the following scenarios:

- operator wearing improper clothing in the area causes ESD discharge initiating an open item during troubleshooting operation (7×10^{-6}/year)
- manipulator gripper/mechanical failure causes an item to drop (1.63×10^{-5}/year)
- manipulator computer/electronic failure causes an item to drop (1.63×10^{-3}/year)

Significant equipment damage scenarios not involving fire or explosion include:

- manipulator computer/electronics failure causes equipment damage (3.7×10^{-2}/year)
- manipulator mechanical failure causes equipment damage (3.7×10^{-2}/year)
- jib crane impact due to human error during maintenance causes equipment damage (1.56×10^{-2}/year)

Similar scenarios to most of these have already been described for other locations in the preparation building. The scenario involving electrostatic discharge from an operator wearing improper clothing is new and is delineated below:

Electrostatic Discharge from Operator During Troubleshooting in Cell 4 (7×10^{-6}/year)

Fault Tree Component No.	Description	Probability/ Frequency Used
16	Item passed	1.0
49	Troubleshooting in cell is required, with open items present	0.03/hr
50	Wears ungrounded shoes	0.001
51	Supervisor doesn't stop him	0.5
52	Other personnel don't stop him	0.7
53	Operator becomes charged (dry days)	0.8
54	Operator discharges to open item/ layer	1.0
55	Discharge is at exposed explosive (engineering estimate)	0.01
56	ESD sufficient to cause initiation	0.02

3.1.6 Cell 5

Cell 5 is the gun ammunition transfer center to cells 4 and 6, and also houses the case dumper, pull-apart, and case cutter operations. The estimated frequency of fire/explosion accidents here are mainly due to the following scenarios:

- operator error involving mechanical assist operations causes item to drop (1.22×10^{-2}/year)
- ether vapor ignition during case cutter operations (2.95×10^{-3}/year)
- explosive contamination collects in mechanical assist machinery resulting in impact initiation (4.33×10^{-5}/year)
- ether vapor ignition during pull-apart operations (7.40×10^{-4}/year)

Other equipment damage scenarios include:

- equipment damage due to impact caused by manipulator computer/electronics failure (3.70×10^{-2}/year)
- equipment damage due to impact caused by manipulator mechanical failure (3.70×10^{-2}/year)
- equipment damage involving heavy equipment operations during maintenance by operator control failure of jib crane (1.56×10^{-4}/year)

Better information is needed on the possibilities of ether vapor evolving from cases to better assess the associated fire/explosion problem. This ether vapor hazard is discussed further in Appendix B.

The ether vapor initiation scenario is delineated in the table below for the case cutter operation:

Ether Vapor Initiation During Case Cutter Operation (2.95×10^{-3}/year)

Fault Tree Component No.	Description	Probability/ Frequency Used
456	Items processed (case cutter)	71/hr
457	Significant ether is released during operation	1.0
459	Ether ignition by mechanical spark	1×10^{-6}
458	Propagation to other flammable items (propellant)	0.5
438	Deluge system activation too late to prevent propagation	0.02

3.1.7 Cell 6

Cell 6 is the projectile defuzing operation. The estimated frequency of fire or explosion accidents here is mainly due to the following scenarios:

- impact initiation from fuze finger failure (6.51×10^{-4}/year)
- fuze drop water tank problem, particularly tank overfilled (with fuzes) or no water in tank (4.57×10^{-4}/year)
- station-to-station transfer equipment causes impact of item against equipment due to computer/electronics failure (3.26×10^{-3}/year)

- explosive contamination collects on equipment surfaces and initiation occurs by defuzer mechanical impact, pinch/friction in cell port door, impact of cell port door, friction in conveyor bearings, pinch/friction in cell door, etc.; (1.64×10^{-3}/year)
- station to station transfer equipment causes drop of item due to computer/electronics failure (1.63×10^{-3}/year)

Other equipment damage scenarios include:

- damage due to impact of station-to-station transfer machine caused by computer/electronics failure (3.71×10^{-2}/year)
- damage due to impact of station-to-station transfer machine caused by mechanical failure (3.71×10^{-3}/year)
- damage due to jib crane operator control failure in moving heavy equipment during maintenance (1.56×10^{-2}/year)

Similar scenarios to most of these have already been described for other locations in the preparation building, particularly in the Cell 3 defuzing area. A station-to-station transfer equipment impact scenario is delineated in the following table.

Fault Tree Component No.	Description	Probability/ Frequency Used
44	Item being handled by sta/sta transfer machine	89/hr
45	Computer/electronics failure, causing impact of item against equipment	8×10^{-4}
46	Impact sufficient for initiation*	1.1×10^{-5}

* This initiation probability is discussed in the Priority 1 report

3.1.8 Distribution Area

The distribution area serves as a shipping-out point, as well as an item packing, cleaning, vacuuming area for processed items. The estimated frequency of fire/explosion accidents here is mainly due to the following scenarios:

- operator error in Cell 6 outlet causes item drop; (1.22×10^{-2}/year)
- an operator mishandling impact initiation occurs during item packing operations (1.22×10^{-2}/year)
- impact of items during driverless tractor operations, causes initiation (8.47×10^{-4}/year)
- item impact during jib crane operations due to operator error causes initiation (6.86×10^{-4}/year)

Other equipment damage scenarios include:

- damage caused by operator error during jib crane operations (6.24×10^{-2}/year)
- damage caused by control failure of jib crane during jib crane operations (1.66×10^{-3}/year)

Similar scenarios to most of these have already been described for other locations in the preparation. The scenario involving operator mishandling from Cell 6 is delineated in the following table:

Fault Tree Component No.	Description	Probability/ Frequency Used
89	Items being received from Cell 6	89/hr
47	Operator mishandling error; item is dropped or impacted (human error)	0.003
43	Impact is sufficient for initiation*	1.1×10^{-5}

* This probability is discussed in the Priority 1 report

3.2 ACCUMULATOR BUILDING AND SMOKELESS POWDER CONVEYOR

Based on the fault tree analysis of the Accumulator System, it is estimated that the probability of major system damage occurring is 0.343 per year. The major scenarios contributing to this value are summarized below:

• Localized Impact Initiation Scenarios (e.g. dropped tools and rough handlings)	0.3024/yr
• Forklift Penetrations of Type III Containers or Equipment	2.61×10^{-2}/yr
• Impingement due to Pinch Valve Boot Leakage	1.25×10^{-2}/yr
• Filled Type III or MKIV Container Impacts	1.38×10^{-3}/yr
• Electrostatic Discharge from an Ungrounded Operator	3.93×10^{-4}/yr

- Frictional Heating due to a Stuck Roller on the Belt Conveyor — 1.66×10^{-4}/yr
- Fire Transfer from the Preparation Building — 1.12×10^{-4}/yr
- Friction at Rubber Receiving Hopper — 3.51×10^{-5}/yr
- Overheated Bearings on Smokeless Powder Conveyor — 2.87×10^{-5}/yr
- Initiation due to Smoking During Maintenance — 2.81×10^{-5}/yr
- Electrostatic Discharge from an Ungrounded Type III Container During Dust Collector Emptying — 2.6×10^{-5}/yr
- Initiation due to Imcompatible Materials in Dust Collector Duct — 2.6×10^{-5}/yr
- Conveyor Drive Motor Fire Transfers to Conveyor or Storage Hopper — 3.08×10^{-6}/yr
- Frictional Initiation of Contamination Between a Type III or MKIV Container and a Stuck Roller on the Gravity Roller Conveyor — 1.82×10^{-6}/yr
- Electrostatic Discharge due to a Non-conductive Gasket or Air Gap at the Load Point Filling Spout — 1.25×10^{-6}/yr

Those categories of scenarios with estimated frequencies above 10^{-5}/year are discussed in the remainder of this section.

Localized Impact Initiation Scenarios (0.3024/year)

The most dominant cut sets in the accumulator fault tree were found to be scenarios in which a fire is caused by an operator dropping a tool or other article onto a layer of propellant (dust or residue) causing initiation to occur by impact. Scenarios in which impact initiation results from rough handling of equipment or tools during maintenance (for example from an operator using the MKIV container lid sealing wrench as a hammer to loosen or tighten the lid) were also included within this category of events. The scenarios in which a tool, container lid, lid sealing wrench, etc. is dropped causing initiation by impact made up the largest portion of these incidents (0.237/year), and the rough handling incidents made up the remaining 0.065/year.

The highest probability scenario in this category was an operator accidentally dropping a tool into a Type III container during emptying of one of the cyclones or dry collectors in the vacuum system. The basic components of this scenario and probability values that were used are provided here:

Fault Tree Component No.	Description	Probability Used
373	Vacuum System Component is being emptied (not a wet separator)	5×10^{-2}/hour (ie 8 vessels every 2 weeks)
374	A tool is dropped into the Type III container at the start of emptying*	5×10^{-3}/trial
375	A thin layer of material is at the drop location	0.1
376	Stimulus causes initiation	1.0
377	Reaction propagates to involve ** a significant amount of material	1.0

* Initiation will not occur once a thick layer of powder is present to cushion the impact. A human error probability of 10^{-2} and a probability of 0.5 for the drop being early are used.

** It is likely that a flame produced in the Type III container will rise to ignite dust still within the hopper being emptied.

In this scenario, the initiation probability of 1 (Component 376) was based on a tool weighing 0.227 kg (0.5 pound) dropped from a height of 0.76m (30 inches) onto an area of $10^{-5}m^2$ (1/8 inch X 1/8 inch). This produces an initiation stimulus level of 1.69×10^{-5} j/m^2 and a corresponding probability of 1.

This problem area can be minimized by enforcing strict management controls. Tools should be tied to the operator on a short cord to break the fall where practical. Personnel should be trained to be aware of the potential for initiating propellant dust by impact.

Forklift Penetrations (2.6×10^{-2}/year)

This category of events involves a forklift impacting and penetrating a Type III container, a cyclone, a dry collector or a dust collector during the emptying operation. If the material inside the container initiates from the event, a fire or explosion would occur. However, even if an initiation does not occur, penetrating an equipment item can shut down the operation for at least several days.

Fault Tree Component No.	Description	Probability Frequency Used
360 and 363	Forklift is used to move a Type III container during vacuum equipment emptying	6.25×10^{-3}/hour
361 and 364	Forklift impacts and penetrates a full Type III container or equipment item	0.001
362 and 365	Penetration results in an initiation and/or major system damage	1.0

Licensing of forklift drivers will serve to minimize this potential hazard.

Impingement Initiation due to a Leak in the Pinch Valve Rubber Boot (1.25×10^{-2}/year)

There are two pneumatically actuated pinch valves in the Accumulator Building. One is below the collection and storage hopper, and the other is below the weigh hopper. The valve below the collection and storage hopper will be kept open, except during infrequent situations in which an unplanned special maintenance requires that propellant be held in the storage hopper. Conversely, the pinch valve below the weigh hopper is actuated each time a Type III or MKIV container is filled. The pinch valve contains a tube shaped, thick walled rubber "boot" which forms a linear closure when air pressure is supplied. After many closures, the boot could develop a leak allowing air to jet into the line. The air jet could initiate propellant granules in the line by impingement if the granules can be accelerated to a high enough velocity.

Data was not available describing the expected failure rate of the pinch valve's rubber boot. A failure probability of 10^{-6}/cycle corresponds to a boot failure of this type occurring about once every 8 years based on an average container filling rate of 30/hour. This failure rate is judged to be reasonable and somewhat conservative, therefore, 10^{-6}/cycle was used in the analysis.

The air supply to the pinch valve is at 100psig. A pressure reducer drops this pressure to 80psig and a relatively long nominal 1/2 inch tube carries the air to the pinch valve. If a massive hole is formed in the rubber boot, the flow within the tube is expected to be subsonic and choked. Therefore, the velocity at the tube exit at the pinch valve will be sonic, or about 302 m/s at the exit conditions. Scaling relations for an unconfined air jet then predict that the jet's center line velocity will be 302 m/s out to 8.3 cm (3.29 inch) and drop to 165 m/s at 15.3 cm (6 inch). Rather, if a smaller hole is formed in the boot (e.g. 0.318 cm, 1/8 inch), the center line velocity is calculated to be 312 m/s out to 2.09 cm (.821 inch) and drop to 85 m/s in 7.62 cm (3 inches) and 43 m/s in 15.2 cm (6 inches). These jet velocities are quite high from an impingement initiation standpoint, but this is very little space to accelerate a large propellant grain to the stream velocity. Small grains could be accelerated to approach the jet velocity and could be ignited by impingement according to available data for propellant grains (for some materials the TIL is as low as 2.85 m/s). It should be noted that high grain velocities can only be obtained when the hopper is fairly empty; otherwise the grain pile will diffuse the jet air flow and restrict particle movements.

This scenario is summarized below:

Fault Tree Component No.	Description	Probability/ Frequency Used
240	Pinch valve rubber boot develops a major leak upon closure $\left(30 \frac{\text{closures}}{\text{hour}} \times 10^{-6} \frac{\text{leaks}}{\text{closure}}\right)$	3×10^{-5}/hour
241	Jet air flow causes impingement of grains at high velocities	0.1 *
242	Impingement stimulus causes initiation	1.0 *
243	Reaction involves a significant amount of propellant material	1.0

* Whether or not the grains can be accelerated to a high enough velocity to cause initiation depends on the size of the hole in the rubber boot. A probability of one in ten for this is judged to be a reasonable conservative estimate.

Impact Initiation of a Filled Type III or MKIV Container (1.38×10^{-3}/year)

Several scenarios were identified in which a filled Type III or MKIV container experiences an impact, for example due to being dropped or swung into an object during a jib crane maneuver. The highest probability scenario in this category was initiation due to being dropped by the jib crane. This scenario is delineated in the following table:

Fault Tree Component No.	Description	Probability/ Frequency Used
207	Jib crane is used to manipulate full Type III or MKIV container	30/hour
209	Hook to container is not securely fastened, resulting in impact initiation	0.001 *
208	Resultant impact causes initiation	1.1×10^{-5} **

* Human error probability

** It should be noted that the value of 1.1×10^{-5} is for dropping a bomb or full munitions item. It is judged to be extremely conservative for a container holding loose propellant. However, in the absence of better data this value was adopted.

Electrostatic Discharge from an Ungrounded Operator (3.93×10^{-4}/year)

A number of scenarios were identified in which an operator wears improper shoes or clothing into an area where propellant or a contaminant is exposed. The operator becomes electrically charged and discharges at the propellant or contaminant resulting in an initiation. A typical scenario of this type is described below:

Fault Tree Component No.	Description	Probability/ Frequency Used
248	Operator wears ungrounded shoes or dielectric clothing into area	1.25×10^{-4}/hr
249	Area supervisor or other personnel do not stop him	0.35
250	The operator develops a charge	0.8
251	The operator discharges at exposed explosive	0.5
252	ESD stimulus causes initiation	0.05
253	Reaction propagates to the bulk of material present.	0.1

The value of 0.8 for the operator developing a charge is related to the fraction of time in a year that the air is dry. The value is conservative in that a person will not necessarily become charged only by wearing ungrounded shoes on a dry day. For example, walking on a carpet is more likely to create a charge than walking on a concrete floor. Nonetheless, strict management controls should be enforced to assure that operators wear proper clothing in the area and cannot develop an electrical charge on their bodies.

<u>Frictional Heating due to a Stuck Roller on the Belt Conveyor</u>
<u>(1.66×10^{-4}/year)</u>

According to reference 1 about 20 percent of bearing failures result in binding. In the extreme, a bearing that is binding will freeze completely and, in the case of the smokeless powder conveyors can cause a stuck roller. When a roller becomes stuck, if the drive motor does not stall due to the increased load, the conveyor belt will continue to rub across the roller over its contact area with the roller. This rubbing will heat the roller due to friction. Transient heat transfer models, described in Appendix D have been used to estimate the temperature rise due to a stuck roller. Top rollers, bottom rollers, the lower end roller, and the various gravity takeup rollers were evaluated using the models. For the top rollers, it was estimated that each roller will experience a load of about 11 kg (23.5 lb) due to the propellant on the belt and the weight of the belt itself. This will generate about 2.9 Btu/min which will raise the temperature to about 250°F (121°C) in an hour. Sixty three percent of this temperature rise would be reached within about five minutes. For the bottom rollers, the temperature is estimated to rise to below 230°F (110°C).

Some propellants have autoignition temperatures as low as 118°C (more typically 200°C), and rubber has an ignition temperature significantly higher. Therefore, some fraction of propellants could be ignited but the belt itself is very unlikely to start burning due to the friction alone.

For the lower end roller, the frictional heating would depend on the belt tension produced by the gravity takeup unit. It was judged that the gravity takeup unit would typically require about 300 lb of weight - the maximum possible gravity takeup load was estimated to be 1000 lb. For the

"typical" belt tension, the stuck roller heating rate was calculated to be 58 Btu/min. This would raise the roller temperature to nearly 1200°F (649°) in an hour, and to about 600°F (316°C) in the first ten minutes. These estimates indicate that if the conveyor continues to operate with the lower end roller frozen, propellant contamination would be ignited and the belt would melt or start to burn. However, it is questionable whether the drive motor would continue to operate under such a heavy load.

Based on these analyses, the probabilities per year of initiation for each type of roller were derived as follows:

top rollers	1.35×10^{-4}/yr
lower end roller	2.34×10^{-5}/yr
upper gravity takeup roller	2.66×10^{-6}/yr
lower roller	3.62×10^{-6}/yr
lower gravity takeup roller	1.33×10^{-6}/yr

The estimated probabilities were due in part to the predicted temperature rise and in part to the number of rollers of a given type that are present.

A typical scenario for a top roller becoming stuck and heated by belt friction is delineated below:

Fault Tree Component No.	Description	Probability/ Frequency Used
85	Bearing fails causing stuck roller	1.8×10^{-4}/hr *
86	Friction heat ignites contaminant or belt	0.1 **
87	Fire propagates to powder on belt	0.005 ***
31	Deluge system response is too slow to prevent significant damage	

* 120 rollers (240 bearings) with a bearing failure intensity of 4×10^{-6}/hr of which 20 percent are binding failures.

** Represents approximate fraction of propellants that would be ignited at the temperature achieved.

*** Initiation of contaminant under belt would not easily propagate to propellant batches on top of belt. Propellant batches on top of belt are spread well apart and generally would not be at the stuck roller at the right time.

Fire Transfer from Preparation Building (1.12×10^{-4}/year)

Scenarios were considered in which a fire in preparation building Cell 5 or an explosion in Cell 6 ignites propellant on the smokeless powder conveyor. The probabilities for fire in Cell 5 and explosion in Cell 6 were derived from the fault trees for the preparation building.

These two types of scenarios are outlined below:

Fire Transfer Due to Fire in Cell 5

Fault Tree Component No.	Description	Probability/ Frequency Used
17	Fire occurs in Cell 5 and transfers to conveyor	5.4×10^{-7}/hr
31	Deluge system response is too slow to prevent propagation	0.02

Fire Transfer Due to Explosion in Cell 6

Fault Tree Component No.	Description	Probability/ Frequency Used
21	Explosion occurs in preparation building	2.45×10^{-6}/hr
22	Explosion blows out blast panels	1.0
23	Blast/fragments penetrate conveyor housing	0.1
24	Blast/fragments cause conveyor fire	0.1 *
31	Deluge system response is too slow to prevent propagation	0.02

* propellant piles are spread far apart on the conveyor

Friction at Rubber Receiving Hopper (3.51×10^{-5}/year)

If the rubber receiving hopper at the conveyor entrance is adjusted (or manufactured too large) to contact the moving conveyor belt,frictional heating will occur where the hopper rubs the conveyor. If the contact force is 2 lb, it is calculated that the temperature at the interface will rise to about 100°F (38°C) in 15 minutes. If the force is 10 lb, about 280°F (139°C) will be

reached within a half hour. These calculations are based on half the energy that is generated being carried away with the belt, and the other half being used to heat up the rubber hopper flaps. These calculations indicate that if the flaps are set to push down on the conveyor belt with a low force (most likely the case) the temperature would not rise significantly. However, if a nominal force (only 10 lb) is applied, the temperature could rise to initiate propellant present. Setting the hopper to contact the belt with such a high force is considered as a severe human error in the scenario described here (i.e. probability less than 10^{-3}):

Fault Tree Component No.	Description	Probability/ Frequency Used
115	Rubber receiving hopper is set too tight against conveyor belt (rubbing occurs)	2.4×10^{-7}/hr *
116	Temperature rise ignites powder present	1.0
117	Fire propagates to powder on belt	1.0 **
31	Deluge system response is too late to prevent propagation	0.02

* Set once per year with a human error probability of 0.001. Once per year may not be conservative in this case.

** Propellant will be dumped at that location each cycle.

Overheated Bearings on Smokeless Powder Conveyor (2.87×10^{-5}/year)

The transient heat transfer models described in the appendix were used to estimate the temperature rise of a roller bearing on the smokeless powder conveyor for the case were binding starts to occur, e.g., lubrication is lost. The weight loading used in the calculations and resultant temperature rise are summarized below for the different rollers in the system:

Roller Location	Load/Bearing (lb)	Heat Generation (Btu/Min)	Temperature Rise Range*	Time for Temperature Rise (Min)
Top Roller	14.5	0.48	105°F (41°C) to 170°F (77°C)	15 to 30
Lower Roller	25.0	0.79	125°F (52°C) to 225°F (77°C)	20 to 35
Lower End Roller	100.5 **	2.2	95°F (35°C) to 250°F (121°C)	10 to 45
Top End Roller (Drive Roller)	36	7.8	180°F (83°C)to 660°F (349°C)	35 to 60

* Range brackets expected result. The low value is based on an optimistic fin geometry and the high value is based on the worst case geometry used in the one dimensional fin model described in the appendix.

** Based on 300 lb of weight in gravity take-up unit.

The worst case rollers for overheating bearings are those that experience the highest loads from the gravity take up unit. These are the rollers at the gravity takeup unit and the top end roller.

A typical overheated bearing scenario (i.e. for the top end roller) is described below:

Fault Tree Component No.	Description	Probability/ Frequency Used
78	A top end roller bearing fails causing overheating to occur	1.6×10^{-6}/hr
79	The hot bearing ignites contaminant present	0.1 *
80	Fire propagates to powder on belt or in storage hopper	0.5 **
31	Deluge system response is too late to prevent propagation	0.02

* This includes a probability of 1 in 10 that a contaminant is present at the bearing and a probability of 1.0 that the bearing temperature causes ignition.

** A spark would be produced which could fall into the storage hopper. The spark may or may not have sufficient energy to cause an ignition once in contact with the propellant in the storage hopper.

Smoking During Maintenance (2.81×10^{-5}/year)

It is clear that smoking must be prohibited and "no smoking" strictly enforced during operation or maintenance and in general anywhere within the perimeter of the operating areas of the WADF facility. This category of scenarios represent an obvious hazard, but have a clear solution (strict management controls), therefore, no further discussion is necessary.

Electrostatic Discharge From an Ungrounded Type III Container During Dust (2.6×10^{-5}/year)

It is judged that the dust collectors will require emptying about once every two weeks. During emptying, a Type III container is partially filled with water and placed beneath the dust collector hopper. The water will prevent dusting and inert the powder that has fallen into the Type III container. If the container is partially filled with water an initiation is not likely. If the water is omitted and the Type III container is not bonded to

the dust collector during the cleaning operation, dust rising from the container could become ignited by an electrostatic discharge. Such a discharge would be caused by a voltage difference developing between the Type III container and the dust collector during the emptying operation. If the material in the dust cloud and/or Type III container is ignited, the resultant fire ball would rise to the dust collector hopper and could ignite material in the hopper. In addition, the operator who is present could be seriously injured during the event.

Fault Tree Component No.	Description	Probability/ Frequency Used
303	Dust collector is emptied (once per 2 weeks)	6.25×10^{-3}/hr
304	Sufficient water is not put into the Type III container prior to emptying	0.001
305	A significant amount of material is present at the time of initiation	1.0
321	The type III container is not bonded to the storage receptacle	0.001
322	The Type III container becomes charged	1.0
323	The Type III container discharges to the storage receptacle or operator	1.0
324	The discharge occurs at the material being dumped or resultant dust cloud	1.0
325	ESD stimulus causes initiation	1.0

Initiation Due to Incompatible Materials in the Dust Collector Duct

(2.1×10^{-5}/year)

Based on the compatibility study presented in the Priority 1 report, it is not likely that incompatible propellants or explosives will be present in the dust collection ducts at the same time, particularly at ambient temperatures. However, in the quantification of this scenario a probability of 1 was used to account for uncertainties and to assure conservatism. Therefore, the estimated frequency for this scenario is judged to be somewhat high.

Fault Tree Component No.	Description	Probability/ Frequency Used
284	A significant dust layer builds up on dust collector duct walls	6.25×10^{-5}/hr
288	Dust layer contains strongly incompatible materials (severe human error)	10^{-4}
289	The incompatibility results in a fire	1.0
290	Reaction spreads to involve a significant amount of material.	1.0

3.3 MECHANICAL REMOVAL BUILDING

3.3.1 Mechanical Removal Building, Cell 2 (Small Band Saw)

The fault tree analysis for the small band saw gave an expected failure frequency of 19.82/yr. The main categories of failure scenarios identified are listed below.

- Impact initiation of sawed "head" of Mk4 depth charges (13.3/yr)
  - due to impact with tray (13.0/yr)
  - due to impact with floor (.255/yr)
- Electrostatic discharge from plastic sheets used to cover sectioned ammunition items (6.24/yr)*
- Initiation during sawing operation (.182/yr)*
  - due to saw blade misalignment (6.5×10^{-2}/yr)
  - due to improper force/speed setting (6.5×10^{-2}/yr)
  - due to thermal initiation (5.2×10^{-2}/yr)
- Initiation of contamination within cell by a dropped tool (5.24×10^{-2})*
- Initiation due to item mishandling (4.22×10^{-2}/yr)
  - due to forklift tine penetration of steel cover of item (4.16×10^{-2}/yr)
  - during jib crane operations (5.72×10^{-4}/yr)
  - during item transfer from DLT to forklift (2.28×10^{-5}/yr)
  - due to drop by forklift (1.37×10^{-5}/yr)
- Initiation of contamination while loading/unloading carrier plate (7.8×10^{-4}/yr)

In many respects, the small band saw is similar to the large band saw in Cell B of the Large Cells described in Section 3.3.5. Not surprisingly, certain scenarios which are dominant for the small band saw analysis are likewise dominant in the large band saw tree. The starred categories (*) above are so similar to the large cell categories that their discussion is deferred until Section 3.3.5. The only change in the cutsets presented there is the throughput rate for the cell, which is 50 items/shift, roughly, in the case of the small band saw.

The remaining categories of scenarios are described in detail below:

Impact Initiation of Residual Explosive in Sawn Heads of Mk4 Depth Charges (13.3/yr)

Two scenarios have been identified involving the impact initiation of explosive left in the head of a Mk4 depth charge after it has been cut from the

main body of the depth charge. The depth charges are placed in a fixture on the carrier plate, three at a time, inclined at an angle so that the saw blade will contact the sloping surface of the depth charge at a right angle. Attached to the end of the carrier plate is a tray into which the "heads" of the charges should drop as they are severed. Both scenarios postulate that the action of the band saw smears some of the now exposed explosive over the lip of the fresh cut. The head then lands on the portion of the lip over which the explosive has been smeared, resulting in an impact initiation. In the first scenario, the head lands in the tray as planned. In the second, a "snag" of the blade on the head in the final stages of the cut throws the sawn head over the tray, where it impacts the floor. The components and failure probabilities are listed below.

Fault Tree Component No.	Description	Probability/ Frequency Used
153	Sawing operation is begun on item	6.25/hr
154	Head falls into tray	1.0
155	Head lands on contaminated lip	.01
156	Impact results in initiation	.05

The frequency for this scenario is 13.0/yr. The explosive in the head will probably be wet due to the coolant used in the sawing process. The initiation probability used in the last item is, therefore, based on threshold initiation levels for 25 percent wet in-process forms of RDX and TNT. A weight of 3 lbs for the head, and a drop of 6" were used in the calculation of the impact energy, and an impact area of 1/8" X 1/8" was used to estimate the impact area. An impact energy per unit area of 20.2×10^4 J/m^2 was calculated. This value is bracketed closely by TIL values for 25 percent wet RDX (16×10^4 J/m^2 to 24×10^4 J/m^2 and 25 percent wet TNT (15×10^4 J/m^2). 20×10^4 J/m^2 was used as a TIL value.

The second scenario is similar.

Fault Tree Component No.	Description	Probability Frequency Used
157	Sawing operation is begun on item	6.25/hr
158	Head is thrown clear of tray	.001
159	Head lands on contaminated lip	.01
160	Impact results in initiation	.98

The frequency for this scenario is .255/yr. The estimate for initiation probability in the last component is based on an extrapolation of 20×10^4 J/m^2 as a TIL value for dampened explosive as described for the previous scenario. The extrapolation is based on a normal probit curve for dry HBX-1.

It is expected that in either of the above cases, the initiation of one pound of explosive in the "head" of the item may cause sympathetic initiation in the three depth charges present. It is strongly recommended that the fixture and carrier plate be redesigned so that the "head" is secured and does not fall freely after sawing.

Initiations due to Mishandling (4.22×10^{-2}/yr)

Several scenarios were identified in which items were initiated by impact due to mishandlings. These scenarios are

- Penetration of the steel case of an item by a forklift tine (4.16×10^{-2}/yr)
- Drop of an item from the jib crane during loading/unloading of the carrier plate (5.72×10^{-4}/yr)
- Rough handling during pickup of item by forklift at the driverless tractor (2.28×10^{-5}/yr)
- Rough handling and drop of an item during forklift transport (1.37×10^{-5}/yr)

The first of these scenarios is described in detail in Section 3.3.5 on the large band saw. As a typical example, the second scenario is presented below.

Fault Tree Component No.	Description	Probability/ Frequency Used
64	Item prepared for sawing	12.5/hr
65	Jib crane used to load item on carrier plate	1.0
67	Operator error causes item to drop	.001
66	Impact results in initiation	1.1×10^{-5}

The probability of initiation is derived from data compiled during Vietnam. 12.5/hr is twice the throughput rate, once for loading and once for unloading. Such incidents may be minimized with strict management controls and proper operator training.

Impact on a Contaminated Fixture While Loading Carrier Plate (7.8×10^{-4})

This scenario consists of a mixture of human errors, in which good housekeeping is neglected, allowing substantial contamination to build up on the carrier plate, and rough handling of an item which ignites the contaminant.

Fault Tree Component No.	Description	Probability Frequency Used
243	Item is loaded aboard fixture using jib crane	6.25/hr
244	Fixture has been left contaminated with explosive	.001
245	Due to rough handling, item impacts fixture	.003
246	Contaminant present at impact point	0.1
247	Contaminant initiates	1.0
248	Propagation to surrounding contamination occurs	0.1

In calculating the energy per unit area for the impact, an item weight of 50 lbs was used, and velocity of 1 ft/sec. An impact area of 1/8" X 1/8" was also used. Energy per unit area was calculated to be 1.05×10^5 J/m^2. This value gives a very high probability of initiation for virtually all explosives of interest.

It is expected that the likely outcome of the scenario is a severe burn for the operator. Strict management controls and ongoing hazard training are again recommended.

3.3.2 Mechanical Removal Building Cell 3 (Hole Sawing Operations)

Based on the fault tree analysis of Cell 3 in the mechanical removal building, for the hole sawing system, it is estimated that the probability of major system damage occurring is 7.606 X 10 per year. The major scenarios contributing to this value are summarized below:

Localized impact initiation	7.291×10^{-2}/yr
Forklift penetration of item	2.626×10^{-3}/yr
Electrostatic discharge from an ungrounded operator	3.554×10^{-4}/yr
Item being dropped during loading, unloading or transporting	1.480×10^{-4}/yr
Cutter dulls and/or breaks-up	1.300×10^{-5}/yr

In the following sections each of the above scenarios are discussed.

Localized Impact Initiation Scenarios (7.291×10^{-2}/yr)

The most dominant cut sets in Cell 3 of the mechanical removal building hole sawing system fault tree were found to be scenarios in which an initiation is caused by the item impacting some contamination (dust or residue of explosive). Dominant was the pinching and/or impacting explosive contamination on the carriage and/or rollers during loading of large and heavy munition items. The scenario in which the munition item impacts some explosive on the equipment causing initiation made up the largest portion of these incidents (7.28×10^{-2}/yr). In the other incidents which made up the remaining 8.69×10^{-4}/yr, tools are dropped, munition items are impacted against other objects/walls, or tools impact explosive contaminants during maintenance procedures.

The basic components of the highest probability scenario and the probability values that were used are as follows:

Fault Tree Component No.	Description	Probability/ Frequency Used
105	Item being processed at mechanical removal building Cell 3	1.25 items/hr
106	Contamination allowed to accumulate on carriage and rollers	1.0×10^{-2} *
107	Dust pinched/impacted during loading of item	1.0
108	Pinch/impact sufficient to cause cause initiation	0.28
109	Reaction propagates to item/other items	1.0×10^{-2}

*Assumed that clean-up procedure were omitted, therefore, a human error of omission probability of 10^{-2} was used.

In this scenario, the initiation probability of 0.28 (Component 108) was based on an empty item weighing 387.8 kg (855 pounds) being lowered by the jib crane at a velocity of 7.62×10^{-2} m/sec (3 in/sec) onto an area of $10^{-5} m^2$ (1/8 inch X 1/8 inch). This produced an initiation stimulus level of 2.79×10^4 J/m^2 and a corresponding probability of 0.28.

This problem can be minimized by the enforcement of strict house cleaning procedures so that explosive contamination is not allowed to accumulate on equipment. All personnel should be made aware of the potential for initiating explosive contaminants by pinch or impact.

Forklift Penetration of Item (2.626×10^{-3}/yr)

The second most dominant category of events involves a forklift truck impacting and penetrating the Mark 25 or 39 mine. If the residual material inside the mine initiates from this impact/penetration a fire or an explosion would result (washed out items can have up to 4.54 kg (10 pounds) of explosive in them). Note, also that each washed out item is only visually inspected to determine the amount of explosive present. Operators could allow items with more than the designated amount of explosive to leave the washout/steamout area and enter the hole sawing facility. Regardless, even if an initiation does not occur, penetrating an item is certainly not recommended. Forklift truck drivers should be well trained and proficient in the operation of forklifts so as not to bump into equipment, walls, etc. since misused/damaged

equipment will interrupt production which would result in lost time and a costly operation. The basic components of this scenario and the probability values that were used in the analysis are as follows:

Fault Tree Component No.	Description	Probability/ Frequency Used
401	Item brought to load/unload area	1.25 items/hr
402	Item washed out(less than 10 lb. of explosive)	1.0
403	Prongs used on item	1.0
404	Prongs at proper height to impact item	10^{-1}
405	Prongs puncture item	10^{-3}
406	Impact sufficient to cause initiation	1.0
407	Reaction propagates to bulk of explosive	10^{-2}

To verify that the forklift truck can indeed penetrate a Mark 25 mine, the analysis was based on a shear strength for mild steel of 2.41×10^8 Pa (35,000 psi) with the forklift truck traveling at 8.05 m/hr (5 mph) and weighing 907.2 kg (2000 pounds). The forklift truck produced an energy of 2268J while it only required 494J to penetrate a mild steel cylinder 56.9 cm (22.4 inches) in diameter and a 0.635 cm (1/4 inch) wall with a fairly sharp prong on the truck. Therefore, there is a good chance that when a forklift truck prong impacts a mine, it will penetrate the wall of the mine.

Electrostatic Discharge From an Ungrounded Operator (3.554×10^{-4}/year)

This category of events involves operators and/or maintenance personnel wearing ungrounded shoes or dielectric clothing. A number of scenarios were identified in which personnel wear improper shoes or clothing into areas where explosives or a contaminant is exposed. The personnel becomes electrically charged and discharges at the explosive or contaminant resulting in an initiation. A typical scenario of this type is as follows:

Fault Tree Component No.	Description	Probability Frequency Used
241	Operator enters cell to service used filter media container	1.923×10^{-2}
242	This operator is wearing ungrounded shoes in area	10^{-3}
243	Supervisor does not stop him	0.5
244	Other personnel do not stop him	0.7
245	Operator develops a charge	0.8
248	Discharges to exposed explosive on filter media	10^{-1}
246	Sufficient energy to cause initiation of explosive	0.12
247	Reaction propagates to bulk of explosive in deep bed filter unit	1.0

The value of 0.8 for the operator developing a charge (component 245) is related to the fraction of time in a year that the air is dry at the Hawthorne facility. The value is conservative in that a person will not necessarily develop a charge simply by wearing ungrounded shoes on a dry day. For example, walking on a carpet or sliding on a car seat is more likely to create a charge than say walking on a concrete floor. Nonetheless, strict management controls should be enforced to assure the personnel wear proper clothing in the area and cannot develop an electrical charge on their bodies and/or clothing.

Cutter Dulls and/or Breaks-up (1.30×10^{-5}/year)

A number of scenarios were identified in which the operator sets the wrong cutter speed and feed, or the cutter controls fail, or cutters are not replaced at regular intervals which results in a dull cutter or cutter break-up especially in a cutting situation such as being performed in Cell 3 (interrupted cuts). A typical scenario of this type is described below:

Fault Tree Component No.	Description	Probability Frequency Used
126	Item being processed in Cell 3	1.25 items/hr
127	Cutter dulls, overheats, and/or breaks up creating temperature rise or sparks	0.2

Fault Tree Component No.	Description	Probability Frequency Used
128	Temperature rise/sparks contact explosive	1.0
129	Thermal initiation results or spark sufficient to cause initiation	2.5×10^{-2}
130	Sufficient amount of explosive to form a train	10^{-6}
131	Coolant jet does not suppress reaction	1.0
132	Reaction propagates to item or other items	1.0

The value of 10^{-6} for sufficient amount of explosive to form a train (component 130) is related to human errors. The first error is at the washout/steamout where the item is not completely washed out. The second human error is when the item is not autoclaved correctly, and finally the last human error is when at the mechanical removal building the operator fails to inspect item prior to loading it into Cell 3 for hole sawing. It is IITRI's belief that the hole cutters will have a very short cutting life due to the interrupted cuts being performed on the item. This short life will interfere with production and will be fairly costly. Nonetheless, strict cutter inspection is recommended (after each item) to make certain cutters are sharp so as to reduce the possibility of cutter break-up.

3.3.3 Mechanical Removal Building, Cell 1 (Punch Press Operation)

Based on the fault tree analysis, the probability for major system damage or personal injury resulting from fire and/or explosion in Cell 1 of the mechanical removal building is 8.502×10^{-2} per year. The major categories of accidents and their contributions to the above accident frequency are given below.

- impact initiation of primer tubes due to mishandling outside of Cell 1 — 8.49×10^{-2}/yr
- initiation of primer tubes due to electrostatic discharge from operator — 9.10×10^{-5}/yr
- initiation due to friction generated by normal shearing process — 8.32×10^{-7}/yr

For the purposes of the analysis, certain judgements were made concerning Cell 1. These judgements were:

(a) Cell 1 will be used for the shearing of primer tubes into lengths which will allow their deactivation in the rotary furnaces.

(b) Average cycle time for the cell is 15 min/cycle, including the time required for loading and unloading the primer tubes onto the carrier plate.

(c) As the carrier plate has not yet been designed, it was necessary to make certain basic assumptions concerning its design. It has been assumed that the carrier plate will carry 25 primer tubes per cycle, held by a "V" notch or some similar design so that the tubes will not roll together, or be pinched flat by the shearing motion. It is assumed some sort of clamping mechanism will hold the primer tubes in place.

In the remainder of this section, the specific scenarios from the above summary will be described in detail.

Impact Initiations Due to Mishandling of Primer Tubes (8.49×10^{-2}/yr)

By far the most dominant scenarios in the Cell 1 fault tree analysis were those involving the mishandling of primer tubes, either by themselves or while in Type II containers. Scenarios from this category include mishandling incidents which take place during transfer of primer tubes to and from the work area of Cell 1. Included are incidents involving the driverless tractor and forklift. These scenarios are described in order of descending likelihood.

The most dominant scenario in this category is the drop of a primer tube by the Cell 1 operator while loading or unloading primer tubes from the carrier plate. The basic components and failure frequencies are:

Fault Tree Component No.	Description	Probability/ Frequency Used
18	Operator loads/unloads primer tube from carrier plate	200/hr
19	Operator drops primer tube	.001
20	Impact initiates primer tube	1.0×10^{-4}
21	Operator injured by fire/explosion	1.0

This scenario has a frequency of 8.32×10^{-2} per year. The dominance of this scenario is due primarily to the high frequency with which this operator must handle the primer tubes. The initiation probability is based on an extrapolation of impingement data for lead azide, the most sensitive to impingement of the materials likely to be present in the detonator of the primer. The threshold initiation level of 25.1 m/sec was used corresponding to an initiation probability of 0.05. A weight of 1 lb.(0.454kg (for the primer tube was used, and a drop height of 1 meter. Given the inevitability of a certain number of mishandlings due to the high number of primer tubes handled, it's strongly recommended that drop tests using actual primer tubes be conducted to substantiate the initiation rate used above. In any event, use of conductive pads around the work area to lessen the initiation probability may be advisable. Also, it is highly recommended that the Cell 1 operator be provided with flame resistant clothing and gloves, as well as safety glasses and full face shield.

The next most dominant failure mode in this category is the drop by the operator of a Type II container while transferring the container between the pallet of containers and the conveyor area. The components and probabilities are given below.

Fault Tree Component No.	Description	Probabilities/ Frequency Used
14	Operator moves Type II container between pallet and work area	4/hr
15	Operator drops container	.001
16	Impact ignites primer tube	1.0×10^{-4}
17	Operator injured by fire/explosion	1.0

This scenario has a failure frequency of 1.66×10^{-3} per year. This scenario is similar to the previous one. Although the primer tubes are in a Type II container which will dissipate the force of impact somewhat, there are more tubes, estimated at 50, involved in a single drop. These factors should roughly offset and the same probability of initiation as used in the previous scenario is used here.

It is recommended regarding this scenario, and others to follow, that drop tests also be done using Type II containers. Layers of padding inside the container, somewhat rigid and notched to resist movement of the primer tubes within, should be tested for effectiveness in cushioning such impacts.

The next most dominant scenarios in this category concerns the mishandling of a pallet of 14 Type II containers containing primer tubes during a transfer by forklift from the driverless tractor to the Cell 1 work area. In this scenario rough handling or reckless driving causes a container to fall off the pallet and initiate.

Component No.	Description	Probability/ Frequency Used
9	Forklift transfers pallet between driverless tractor and Cell 1 work area	.14/hr
11	Container is dropped due to forklift operator error (collision, rough handling)	.001
10	Impact initiates primer tube in Type II container	1.0×10^{-4}

The failure frequency for this scenario is 5.84×10^{-5}/yr. Strict control and supervision of forklift operation, and as well as the tests recommended

for the previous scenario, are recommended to minimize the probability for this scenario.

The next scenario is similar to the forklift scenario, but concerns the driverless tractor.

Fault Tree Component No.	Description	Probability/ Frequency Used
1	Driverless tractor driven manually during approach/departure	.14/hr
2	Operator error while driving	.001
3	Error causes jolt	0.2
4	Jolt causes container to fall from pallet	0.5
5	Impact results in initiation	1.0×10^{-4}

The failure frequency for this scenario is 5.82×10^{-6} per year. The recommendations made in the forklift section are also relevant here.

Initiations Due to Electrostatic Discharge (9.10×10^{-5}/year)

This category is represented by a scenario in which failure of the operator to wear proper clothing and/or conductive shoes results in an electrostatic discharge which ignites a primer tube. The components and probabilities are:

Fault Tree Component No.	Description	Probability/ Frequency Used
22	Operator begins shift	.125/hr
26	Operator wears improper shoes/ clothing	.001
27	Supervisor does not stop him	.5
28	Other workers do not stop him	.7
23	Operator carries charge	.05
24	Discharge occurs in proximity to exposed explosive	.01
25	Discharge ignites explosive in primer tube	1.0

The failure frequency for this scenario is 9.10×10^{-5}. ESD is especially hazardous while handling primer tubes because of the explosive exposed through

perforations on the tube, and black powder dust present on the carrier tray as a result of the shearing operation. Good housekeeping is essential here. It is strongly recommended that a device be installed in the workers' locker room on which they must step for a check for conductivity before reporting to their work stations. Each worker can be required to sign a log book verifying he has performed the test. This process will also serve as a safety reminder to the workers immediately before reporting to work.

Initiation Due to Friction Generated by Normal Shearing Process (8.32×10^{-6}/year)

During most shearing operations, the lower surface of the shearing tool is not perpendicular to the direction of the shearing motion, but at an angle (see figure 1). This results in a component of the resisting force pushing the shearing tool against the part of the work which has already been sheared. The rubbing induced by this force could result in an initiation due to friction. This scenario can take place during the course of the normal shearing process, and does not require any failure to occur. The components and probabilities for this scenario are listed below.

Fault Tree Component No.	Description	Probability/ Frequency Use
36	Primer tubes sheared by press	200/hr
37	Friction generated by shearing results in initiation	1.0×10^{-12}

The expected frequency for this scenario is 8.32×10^{-6}. Although the initiation probability per shear is quite low, the large number of tubes sheared result in a significant hazard. The analysis was based on a shearing with an angle of 30°, a shear strength for the steel of the tube of 50,000 psi, and a speed of shear of 1/4"/sec. The calculated normal force is 4×10^{8} N/m^2. This analysis is conservative. It is strongly recommended that primer tubes with simulants be instrumented to record this normal force and run through the shearing operation.

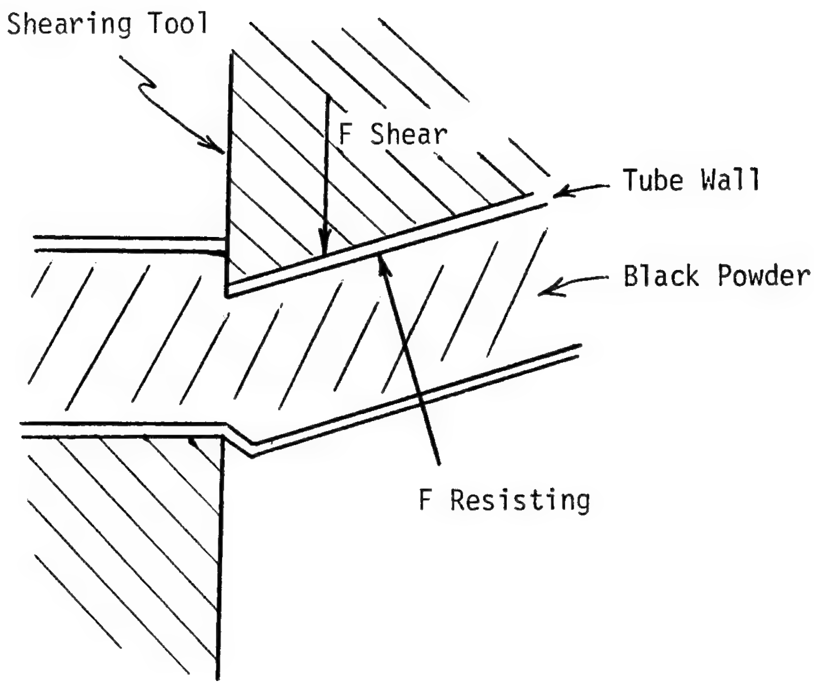

Figure 1. Normal Shearing Process

3.3.4 Large Cell C (Unscrew Machine)

Results of the fault tree analysis of the Large Cell C operations indi-ate a category I or II accident frequency of 1.31×10^{-3} per year, excluding injuries and illnesses of various causes. In the analysis of Large Cell C, the average production rate was taken to be 2.29 projectiles per hour. The individual rates for the different types of items processed in Cell C were averaged to estimate this rate. In the analysis, items were assumed to be brought by truck to the large cells and carted away by driverless tractors.

The most serious incidents considered are those involving explosion and fire because of the high potential of human and property losses. The fault tree analysis has shown that the most probable are those involving operator errors with forklifts, operator error involving monorail crane operation, and operator error causing fuze impact during the normal defuzing operation. These particular scenarios are discussed below.

Item Impact Initiation due to Forklift Operational Errors (3.49×10^{-4}/year)

Due to the relatively high time span of forklift operations the potential for items mishandling incidents is very high here. One particular scenario is that of an operator inadvertently driving a forklift into items, causing an impact sufficient for initiation. This particular scenario has an estimated frequency of 3.49×10^{-4} per year. It is described on the summary table below.

Fault Tree Component No.	Description	Probability/ Frequency Used
40	Large projectiles being loaded/ unloaded at large cell	2.54/hr
41	Forklift used for unloading	1.0
43	Forklift used near items	1.0
44	Forklift inadvertently driven into items due to operator error	0.003
42	Resultant impact is sufficient for initiation	1.1×10^{-5}

Item Drop Impact Initiation During Monorail Operations (3.14×10^{-4}/year)

Another incident involving item initiation due to hard impact is that during monorail crane operations. The scenario here with the highest frequency of occurrence is one involving human error with the use of the crane controls, causing the item to drop during crane maneuvers. This particular incident has a frequency of 3.14×10^{-4} per year.

Fault Tree Component No.	Description	Probability/ Frequency Used
20	Projectiles being prepared at Large Cell A	1.0
21	Monorail used to transport item to Cell C	2.29/hr
28	Item is dropped during crane maneuvers due to operator control failure (human error)	0.003
22	Impact is sufficient for initiation	1.1×10^{-5}

Fuze Impact Initiation During Manual Defuzing Operation (1.05×10^{-4}/year)

After a base plate is removed from a projectile, the base fuze must be removed manually. This is done by first cleaning the base plate and fuze of all explosive contamination using a wooden scraper and hot water. Then the plate is secured in a vise and the fuze is removed using hand tools. If the item is struck or scraped with the wrong type of tool during this operation, fuze initation may result. Also, if the item is dropped during these manual procedures, fuze initiation may be possible.

This scenario is summarized below.

Fault Tree Component No.	Description	Probability/ Frequency Used
116	Item in defuzing operation	2.29/hr
126	Item dropped or struck during manual fuze removal	0.001
127	Resultant impact is sufficient for initiation	1.1×10^{-5}

Other Potential Hazards in Cell C

Other hazards of concern is large Cell C include the following:

- Since all of the large projectiles contain Yellow D, there may be an operator exposure problem, particularly during the base plate/fuze cleaning operations.
- Since all of the large projectiles weigh from 105 to 2700 pounds, there is concern for operator safety in all phases of item transfer operations.

3.3.5 Large Band Saw (Large Cell B)

The fault tree analysis of the large band saw yielded an expected frequency of 2.17/year of major system damage occurring. The primary categories of scenarios producing this extremely high rate are summarized below:

- Electrostatic Discharge from Plastic Sheet used to Cover Sectioned Item (1.59/year)
- Initiation During Sawing (0.198/year)
- Equipment Damage Scenarios (0.17/year)
- Initiation of Full or Sectioned Items due to Mishandlings (0.153/year)
    - due to Forklift operations (0.132/year)
    - due to Impact of a Sectioned Item (1.87×10^{-2}/year)
    - due to Impact of a Full Item (2.19×10^{-3}/year)
- Initiation due to a Tool Being Dropped onto Contamination (5.24×10^{-2}/year)
- Initiation of Contamination While Item is Lowered onto Saw Platten (8.27×10^{-3}/year)
- Operator ESD Initiation (1.17×10^{-4}/year)

In the following paragraphs each of these categories of scenarios are discussed.

Electrostatic Discharge from Plastic Sheet Used to Cover Sectioned Item (1.59/year)

It is the current intention to cover sectioned items with a plastic sheet to minimize the possibility of contaminating the surrounding area during temporary storage or transport. In reference 2 it was mentioned that this is current practice at Hawthorne NAD. Calculations indicate that the energy produced in a single discharge from a dielectric surface of this type would be on the order of 2.2 mj. This result was obtained by several methods, and one of the approaches is presented in Appendix E. An energy of 2.2 mj corresponds to an initiation probability of about 3×10^{-4} for HBX-1. Although this probability is well below what is normally considered to be the "threshold level" the 5 percent threshold initiation level should not be considered to be an absolute lower bound for the possibility for initiation to occur. This overall scenario involves the basic events described below:

Fault Tree Component No.	Description	Probability/ Frequency Used
182 183	Sectioned item is transported to work point B	1.59/hr
184	Plastic sheet is used to cover exposed sectioned item	1.0
185	ESD from plastic sheet occurs (dry day)	0.8
186	Sectioned item is initiated due to ESD from plastic cover	3×10^{-4}

The surface of the item may be moist after the cutting operation due to the coolant, and this will reduce the immediate charging hazard. However, the item will then be stored and transported with the plastic cover in place. It will eventually dry off and the plastic could develop a charge then. Therefore, it is strongly recommended that untreated plastic covers not be used on the sectioned mines. Rather, the mines should be covered with a high conductivity, low permittivity material, for example conductive plastic, paper or treated cloth. "Antistatic agents are available for surface or bulk treatments of fabrics or plastics which depend in principle on capturing surface films of moisture" (ref. 3). However, such treatments are temporary at best, and wear off with time. Conductive plastic is, therefore, preferable.

Initiation During Sawing (0.198/year)

The probability of initiation during sawing operations was derived based on the data available in reference 2. Initiation during sawing can occur by several means. The relative probabilistic ranking of these sawing hazards are:

1. Saw force and/or speed set wrong causing initiation (9.92×10^{-2}/year)
2. Initiation due to saw blade breaking due to misalignment (6.61×10^{-2}/year)
3. Thermal initiation during normal sawing (3.31×10^{-2}/year)
4. Initiation due to loss of coolant (3.98×10^{-6}/year)

Based on the hazards analysis presented in the Batelle report (ref. 2) for the band saw operations, the probability of thermal initiation was taken to be 5×10^{-6}, the "worst case" shown for sawing with coolant present. For loss of coolant, the "worst case" value for 4 teeth per inch cutting without coolant was used, 1×10^{-4}. For sawing with the wrong speed and/or force

setting, a probability of 2.5 X 10^{-2} was used, corresponding to the "worst case" conditions for all the cases considered in the reference 2 study except for the Rockeye. The Rockeye was estimated to have a thermal initiation probability of 1 in all cases due to its thin wall. A lower force was recommended for the Rockeye and similar items. This case indicates that the initiation probability may be higher than 2.5 X 10^{-2} if the force and/or cutting speed are set wrong.

The results in reference 2 for cutting through contaminated empty items with loose internal tubing were even higher in some cases, up to 0.12 for the MK39 Mine. In these cases, cutting through loose tubing inside the item would not be effectively protected by a coolant. Therefore, cutting empty contaminated items will be significantly more likely to result in an initiation than cutting full items. Naturally, the consequence of an initiation of a full item is significantly worse however.

A typical scenario in this category is presented here:

Fault Tree Component No.	Description	Probability/ Frequency Use
304	Item is brought to Cell B for sawing	1.59/hr
307	Saw force is set wrong (operator reads settings incorrectly)	0.001
308	Blade applies too much force for the particular item being cut	0.1
310	Heat buildup is not dissipated due to type of item, and an initiation results	2.5 X 10^{-2}

It is clear that the sawing operation is inherently quite hazardous. Strict management controls must be enforced to insure that the proper force and saw speed are used for the particular item to be cut. If a contaminated empty item is to be sawed, the initiation probability can be significantly higher than for a full item and sawing conditions must be adjusted.

Equipment Damage Scenarios (0.17/year)

A variety of "non-fire or explosion" scenarios were identified in which the equipment in Cell B could be seriously damaged. These scenarios include the

band saw being damaged by the forklift due to the operator being careless or inattentive, an item falling from a forklift or from the bridge crane onto the band saw, or being swung into the band saw, etc. A typical scenario in this category is delineated in the table below:

Fault Tree Component No.	Description	Probability/ Frequency Used
411	Item brought inside Cell B by Bridge Crane	1.59/hr
414	Operator allows hoisted item to ram band saw	10^{-2}
415	Major damage to band saw occurs (by engineering judgement)	10^{-3}

Initiation of an Item by Forklift Penetration (1.32×10^{-1}/year) or Initiation of Sectioned Item by Impact (1.87×10^{-2}/year) or Initiation of a Full Item by Impact (2.19×10^{-3}/year)

The next three categories of scenarios are similar in many respects and are combined in this section. They involve an error or control failure leading to a full or sectioned item being mishandled. Based on data from the Vietnam war, discussed in the Priority 1 report, a finite probability has been derived for initiation of items by impacts due to mishandling (e.g. due to dropping the item). The derived initiation probability is 1.1×10^{-5} per trial. It is considered that a sectioned item impacting at the open end has a much higher probability of initiation. The item is quite heavy and would ignite contamination at the impact point. The reaction is then likely to propagate to the adjacent explosive exposed at the cut plane. Similarly, forklift penetrations of full or sectioned items are considered to be much more likely to cause initiation due to the hot deformed metal coming into direct contact with the explosive.

Calculations of energy required to penetrate a mine or bomb (0.25 inch steel wall) indicate that penetration could occur due to a forklift impact. A geometry effect must be included, however, to account for the prong hitting within a relatively narrow region on the item. Otherwise, either the bomb or the prongs will move, reducing the energy available for penetration.

A typical item initiation scenario is delineated below:

Fault Tree Component No.	Description	Probability/ Frequency Used
87	Forklift arrives at staging area to unload item	1.59/hr
88	Driver misses pallet driving too fast (human error probability)	0.001
89	Forklift prong impacts and penetrates through casing	0.01*
90	Penetration stimulus causes initiation	1.0

* Geometry factor for location of hit and factor for speed being high enough to cause penetration

Impact Initiation of Contamination by Tool Being Dropped (5.24×10^{-2}/year)

The primary scenario involving local impact initiation due to an operator dropping a tool onto contamination was found to occur during servicing of the filter media. In this case an operator is injured due to a flash fire occurring, and significant damage to equipment does not occur.

Fault Tree Component No.	Description	Probability/ Frequency Used
393	Operator enters cell to service filter media (once every 40 hours)	2.52×10^{-2}/hr
394	Operator allows contamination to fall on floor while pulling filter media out of container	0.5
395	Operator drops tool on contamination	10^{-2}
396	Impact stimulus initiates contamination (sensitivity data for dry HBX-1 Used)	1.0
397	Flash fire results, i.e. fire propagates to filter media and contamination	0.1
398	Operator is severely burned due to flash fire	1.0

Item Initiates Contamination While Being Lowered onto the Platten
(8.27×10^{-3}/year)

If the saw platten is not cleaned between operations, a mixture of explosive and metal chips will be impacted or pinched each time an item is lowered onto the platten. If this contamination is wet from coolant, the material is not expected to be easily ignited. However, some fraction of the time the explosive will be allowed to dry somewhat. Although probit impact sensitivity data is not available for such moist materials, initiation is expected to be likely in this case. Then propagation of the reaction into a sectioned item could produce an explosion

Fault Tree Component No.	Description	Probability Frequency Used
399	Large cell is not cleaned of explosive particles after sectioning of each item (human error probability)	0.001
400	Explosive particles accumulate	1.0
401	Items are brought to Cell B for sectioning and sectioning is accomplished	1.59/hr
406	Sectioned item is hoisted up off saw platten	1.0
407	Item is lowered back onto saw platten	0.05
408	Lip of sectioned item impacts explosive contamination	0.5*
409	Initiation of contamination ignites exposed explosive of sectioned item	0.05 **
410	Fire or explosion results	1.0

* One end will be slightly lower than the other. There is a 50% chance that the low end is the one with exposed explosive.

** The impact stimulus is estimated to be 1.51×10^{-5} j/m^2. This corresponds to a probability of 1 for dry explosive. A factor of 0.05 is added to account for the fraction of time that the contamination is relatively dry. The resultant reaction would be very near the exposed explosive in the sectioned item and propagation is likely.

Electrostatic Discharge Initiation from an Ungrounded Operator
(1.17×10^{-4}/year)

The scenario in which an operator wears ungrounded shoes into the area has shown up for much of the rest of the WADF system. In this case, the computed probability of 1.17×10^{-4}/year may be somewhat conservative in that the filter

media is generally wet, whereas sensitivity data for dry HBX-1 was used in the calculation. It should be noted, however, that there will be times when the filter media is serviced after it has had a chance to dry.

Fault Tree Component No.	Description	Probability Frequency Used
384	Operator enters cell to service filter media	2.5×10^{-2}/hr
385	Operator is not wearing grounded shoes	0.001
386	The supervisor or other personnel do not stop him	0.35
387	Operator walks across floor and becomes charged (dry day)	0.8
388	Operator discharges to filter media container (layout of area and job to be done)	0.1
390	ESD has sufficient energy to initiate explosive on the filter (sensitivity for dry HBX-1)	0.02
391	Flash fire results	1.0
392	Operator is severely burned	1.0

4. RECOMMENDATIONS AND CONCLUSIONS

In this section, the recommendations and conclusions resulting from the Priority 2 hazards analyses are consolidated. They are presented for each area of the facility that was evaluated under Priority 2 and have been prioritized using descriptive terms such as (in decreasing order of urgency) "strongly recommended", "recommended", "suggested/good practice", and "concluded". General recommendations that apply to more than one area are presented separately at the end of the section.

4.1 PREPARATION BUILDING

- It is recommended that cartridge cases to be processed in the preparation building be tested to determine if a flammable mixture of volatile vapors with air is present in the void spaces in the case. Naturally, this is only relevant for cases containing propellant that was manufactured by a solvent process. Analyses conducted in this study indicated that a flammable mixture may be present, but there were significant uncertainities in the analyses to determine this for sure. Therefore, an experimental solution is warranted. A gas sample can be extracted from a closed cartridge case by drilling a small hole into the case, or a flammable gas detector can be used to monitor the gas while cases are opened. In both tests precautions must be exercised to prevent and guard against an ignition of the gases or propellant in the case. If uncertainty remains even after such testing, it is recommended that a flammable gas detector be installed in the vicinity of the case cutter and pull apart machines to warn operators of the presence of a flammable gas during the operation of Cell 5.

- It is imperative that a water cushion be present at all times for fuzes dropped into the "fuze drop" tanks in Cells 3 and 6. It is possible that the operators will allow this tank to become empty (no water) or to become overfilled with fuzes. In either case, a finite probability exists for initiation of the fuzes by impact. Therefore, it is recommended that a sensor be installed to warn the operators of insufficient water at the start of an operation and of too many fuzes during the operation. This could be accomplished by sensing the weight of the tank. Prior to operation, the weight must be at least that of a water filled container or the operation cannot begin by interlock. During operation, if the weight exceeds the level at which fuzes are no longer protected by a significant layer

of water, a warning should be actuated. Alternate solutions to this problem should be evaluated.

- Preparation Building, Cell 1, is now earmarked for storage of "unsafe" items "... until enough of them accumulate to be taken to the disposal site". This is a blatantly unsafe practice and it is recommended that it not be done. Should an "unsafe" or "suspect" round or item be detected, its disposal--or at the very least, its removal from a busy operating building--should be immediate, and under strict control. To do any less than this would be a highly unsafe act. Removal, after all, should pose no major hardship. Based on the combined assumed throughput rates of cell 3, and cells 4-5-6, and the 1 per 1000 "suspect" item incidence projected, we're only talking about 3 per day.

- It is anticipated that the robot manipulators will require frequent preventive maintenance to minimize the possibility of mechanical or control failures that can result in impacts causing equipment damage and/or initiation of munitions items being handled.

- It is recommended that partitions be constructed to better isolate the different individual work stations in the Preparation Building corridor, receiving area, and distribution area. Currently, if an incident occurs which causes a round or item to fire or detonate, personnel at other work stations are in a direct path for serious injury by blast, fragments or an accidentally launched projectile. Isolating personnel to the extent practical with partitions will at least increase their protection against fragments and projectiles.

- For the various unscrewing operations in the Preparation Building and elsewhere, it is suggested that consideration be given to spraying the threaded areas with a compatible penetrating lubricant before attempting to unscrew the parts. This could improve the safety of the operation by wetting any trace contaminants which may be present, and by minimizing the force required to loosen the stuck threads.

4.2 ACCUMULATOR SYSTEM

- It is recommended that the rubber boots inside the pinch valves in the accumulator building be periodically inspected for wear that could lead to a major leak. The rubber boots or pinch valves should be repaired or replaced if such wear is observed. A large leak in the rubber boot could lead to impingement initiation of small propellant grains being processed.

- Bearing failure in the smokeless powder conveyor can result in a fire due to frictional heating at a stuck roller or due to a bearing overheating. It is recommended that the roller bearings in the smokeless powder conveyor be inspected and maintained frequently. A conservative inspection/maintenance aid part replacement schedule should be established based on the manufacturers reliability data for the bearings in use. With regard to overheated bearings, periodic infrared photographs during the operation or strategically placed infrared sensor might be useful to sense the onset of the bearing failure.

- Care should be taken during the setup of the rubber receiving hopper to assure that it does not push too tightly against the moving conveyor belt. Calculations indicated that a nominal force (10 lb) could result in a significant temperature rise at the interface.

- Whenever a powder or granular material is emptied from one vessel or hopper into another container, the possibility exists that a significant voltage difference will develop between the two containers due to electrostatic charging. If the voltage difference is high enough, a discharge can occur between the containers or to another object, for example to an operator. Such a discharge could ignite the material being transferred. Therefore, it is strongly recommended that positive electrical bonding be assured between the weigh hopper and the Type III or MKIV container being filled in the accumulator system, as well as between the various dust collector and vacuum system hoppers and the Type III container used during system emptying operations. A reasonable assurance of bonding can be achieved by placing the Type III or MKIV container onto a conductive rubber covered metal platform (or the roller conveyor in the case of the filling operation) that is permanently bonded to the equipment item being emptied. The platform must be kept clean or its effectiveness will be lost. In addition, a separate bonding strap should be manually connected between the hopper being emptied and the container being filled. This redundancy affords some degree of assurance that bonding will be achieved only as long as the electrical contacts are clean and secure.

- The dust collector and vacuum system ducts should be inspected and cleaned frequently to avoid any significant buildup of a propellant dust layer inside the ducts. Periodically flushing out (e.g. with hot water) should be considered to minimize the buildup. Materials handled by the dust collector and vacuum systems should be checked to assure compatability at the temperatures to which they will be exposed inside the ducts.

- Preparation Building, Cell 5, and the Accumulator Building, together, present a unique problem, viz., segregation and control of "dissimilar" propellants. Propellants dumped in Cell 5, are to be conveyed to the Accumulator Building for packaging"... for storage or for sale". Care must be taken in both locations, therefore, to prevent uncontrolled mixing of different propellant types. Each propellant formulation must be separately and individually packaged because mixing -- although not hazardous per se--would pose a serious problem or threat to a buyer, in the event of sale. Processing methods for reclamation or reuse of double- or triple-base propellants (eg., M26 or M30) are much different than those for single-base (eg., M1, M6, or BS-NACO). To mix them together would cause an intollerable, and potentially hazardous, problem in certain cases. For example, introduction of NG into a process designed to recover NC from single-base propellants would create a real safety hazard.

check procedures to prevent as part of pre-op

4.3 MECHANICAL REMOVAL BUILDING

The analyses of the mechanical removal building included the punch press operation (Cell 1), the small band saw operation (Cell 2), and the hole sawing operation (Cell 3).

4.3.1 Punch Press Operation (Cell 1)

The hazards analysis of the punch press operation was based on the assumption that long primer tubes will be segmented in Cell 1. If primer tubes are to be processed in Cell 1, the following recommendations are provided:

- It is recommended that drop tests be carried out on primer tubes in order to accurately determine their response to this stimulus. Should such tests show a significant probability of initiation, it is strongly recommended that additional tests be carried out to determine the response of primer tubes enclosed in a Type II container to impact, and to test various methods of cushioning within the container to prevent such initiations.

Plant must check

- It is strongly recommended that primer tubes be instrumented and subjected to the shearing operation to determine functional forces which arise during the shearing operation. Small amounts of black powder may be included in these tests to determine characteristic response data.

Plant must check

- These tests should be done prior to the startup of the Cell 1 operation. If initiation is likely, the extent of damage to the cell due to an individual primer tube being ignited and due to a Type II container filled with primer tubes being initiated should be evaluated based on simulation testing. It is conceiveable that the consequence of an initiation, e.g. during shearing, can be tolerated in this case.

check limits for wall damage

4.3.2 Small Band Saw Operation (Cell 2)

- The small and large band saw operations are quite similar in many respects. Therefore, many of the recommendations made for the large band saw apply here also (see Section 4.4.2)

- In the small band saw operation, the "head" of the item will either fall into a tray, or be thrown after sawing is completed. In either case, the initiation of a significant amount of explosive in the head (about one pound) is expected. Sympathetic detonation of the three depth charges in the fixture could also occur, resulting in major system damage. It is strongly recommended that the fixture and carrier plate be redesigned so that the "head" of the item is secured and does not fall freely after sawing. agree.

4.3.3. Hole Sawing Operations (Cell 3)

- It is strongly recommended that a conservative inspection and replacement schedule be developed for the cutters to be used in Cell 3. It is expected that these cutters will generally have a short life span and will require frequent replacement. A dull or broken cutter can result in initiation inside a munitions item being processed in the cell. check maintenance frequency

- It is strongly recommended that operating parameters be derived for the hole sawing operation, such as was accomplished for band saws and hacksaws in reference 2. It is expected that criteria for teeth per inch, cutting force and cutting speed must be carefully defined for each item to be processed to minimize the probability of initiation during cutting. is this available or defined?

- It should be noted that the most hazardous condition during hole sawing will be cases where the hole is not positioned correctly and loose internal plumbing is sawed into (by analogy with the band saw results presented in reference 2). In these cases, increased frictional heating occurs due to cocking of the loose internal part, while exposure to coolant is restricted. In addition, relatively large quantities of explosive could remain hidden behind the internal plumbing and become ignited.

4.4 LARGE CELLS

The two active operations in the Large Cell area were analyzed for potential hazards. These were the unscrew machine (Cell C), and the large band saw (Cell B). Cell A is presently empty and did not require a hazards analysis.

4.4.1 Unscrew Machine (Cell C)

- The manual removal of the base fuze and associated cleaning of the base plate and fuze are considered to be inherently hazardous operations. If the item is struck or scraped with the wrong type of tool, fuze initiation may result. In addition, the items are filled with highly toxic yellow D, and the operator could be exposed to this chemical. Plant must decide

4.4.2 Large Band Saw (Cell B)

- It is strongly recommended that an untreated nonconductive plastic sheet not be used to cover items sectioned at Cell B. Rather, the sectioned items should be covered with a relatively high conductivity, low permittivity material, for example conductive plastic, paper or treated cloth. Otherwise, an electrostatic discharge from the plastic sheet has a finite probability to initiate the exposed explosive. Can we do?

- The sawing operation is inherently hazardous. Strict management controls must be enforced to insure that the proper force and saw cutting speed are used for the particular item to be cut. If a contaminated empty item is to be sawed, the initiation probability can be significantly higher than for a full item (from reference 2 analysis) and the sawing conditions must be adjusted to account for this. While sawing contaminated empty items internal plumbing should be avoided, because this is where thermal initiation is most likely. agree

4.5 GENERAL RECOMMENDATIONS FOR THE PRIORITY 2 SYSTEMS

Many of the general recommendations presented for the Priority 1 Systems are pertinent here also. These recommendations are repeated below:

- Every operation on every equipment item must be covered by a written procedure, reviewed and approved by operating and safety management personnel.

- A comprehensive training program should be required for all plant personnel, including information on potential hazards.

- All equipment operators should be given appropriate training courses and certified or licensed for operations in which they will be involved.

- All plant personnel should be tested for electrical grounding of footgear at least once a day with a sign-in sheet.

- Frequent cleanup of each plant area is mandatory to prevent buildup of contamination. Such cleanups should be scheduled as part of the operating procedures for each area.

- Area surfaces should be kept wet during maintenance as part of the procedure. The equipment should be thoroughly cleaned/decontaminated prior to any maintenance operation.

- It is recommended that a 2 locker system be adopted for plant personnel. One locker should be for street clothes and a second locker for work clothes. All clothing should be changed at the beginning and end of the shift. Clothing should be supplied by the plant - nothing taken home. A shower should be taken enroute from taking off work clothes to putting on street clothes. This procedure will also help avoid street shoes being mistakenly worn in the plant areas.

- An area entry and hot work permit program should be set up to assure that all temporary repairs and maintenance operations are well thought out and accomplished with several levels of management checks.

- During maintenance, tools should be connected to the workmen by a cord wherever practical to help break the fall of the tool if it is dropped.

- Strict cleanliness must be enforced at all times in the plant, particularly when personnel leave contaminated areas to go to lunch or at the end of the shift. Nothing should be eaten in the work area. No food should be allowed in the work area.

- A medical surveillance program should be set up to screen personnel for specific jobs at hiring and to assure that long term health damage is avoided.

- Any major system modifications made in the future should be safety analyzed upon completion of their design.

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APPENDIX A

HAZARDS ANALYSIS APPROACH

APPENDIX A HAZARDS ANALYSIS APPROACH

Basically, the following steps were used in the analyses:

a) Collect Available Information

b) Review Information/Learn System

c) Conduct an Informal Failure Modes and Effects Analysis (FMEA)

d) Develop Fault Tree Logic Diagrams for System (FTA)

e) Quantify Fault Tree (derive scenario probabilities)

f) Interpret and Summarize the FTA Results

For the purposes of this program, the failure modes and effects analyses served to identify types of consequences and types of scenarios to be expected in different areas of the WADF. The FMEA's were used to learn the system and guide the development of the fault trees. Fault tree analysis was the primary methodology used to identify and quantify credible hazards at the facility. The FMEA and Fault Tree methods are described below:

A.1. FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Failure Modes and Effects Analysis is a relatively simple and direct approach for identifying basic sources of failure and their consequences. This method is not rigid and can be used for widely differing applications. It is especially applicable for identifying sources of malfunctions in hardware systems or in process equipment. The primary purpose of the analysis is to identify and remove failures that can cause hazards. However, as a side benefit, the analysis also leads to the identification of failures that are in themselves not hazardous but might affect the reliability of the functioning of a system. The results of such an analysis also may serve as an input to a Fault Tree Analysis, although more generally the two methods are used independently.

A Failure Modes and Effects Analysis is carried out by filling in a table having column headings such as the ones shown in Figure A1. This format is the one used for the Priority 1 systems. The first two columns list the

Systems/ Task	Component	Initial Failure	Chain of Events	Consequence

Figure A1 Failure Modes and Effects Analysis Format Used for Priority 1 Systems

system parts and procedure steps obtained from the available drawings, written descriptions, etc. The third column is used to identify the different possible failure modes for each entry listed in the previous columns. There may be several entries in column 3 for each system part or task. Given these initial failures, the possible chains of events were described in the next column, and the ultimate effect on the system was given in the last column. The Priority 1 FMEA tables were relatively formal and time consuming to produce. These tables were used primarily as "shopping lists" for fault tree development, a function not necessitating the formal presentation. In Priority 2 and 3 analyses a less formal FMEA presentation is being utilized, although this method is still used to provide the basis for fault tree diagramming.

A.2. FAULT TREE ANALYSIS

A powerful method that has developed rapidly since 1962 is the Fault Tree Analysis. This method may be viewed as a systematic and comprehensive investigation of a postulated accident before it occurs. The term "accident" in this case is used to signify any kind of undesired event. The procedure is to define this undesired event and to identify all immediate causes that could have brought it about. These causes, in turn, are traced back through the system until one arrives at the ultimate causes that initiated the sequence of events that led to the undesired event. These ultimate causes may be failures of individual hardware components, or human errors, or other factors which either singly or in combination could have initiated the hazardous action.

An immediate result of such an analysis is a highly visible graphical representation of all basic failures and the paths whereby they can combine to create the undesired event. The method also can be used quantitatively. If data are available for the probability of occurrence of the basic failures, it is possible to calculate the probability of occurrence of the undesired event. In doing so it is also possible to identify those basic failures that are most critical, and the most critical sets of events (scenarios), so priorities can be established for taking corrective action.

An analysis begins by identifying an Undesired Event whose causes are to be traced. Graphically, this event is placed at the top of the page and

represents the base of a tree whose branches are developed and extend downward. Once the undesired event, also called a Top Event is specified, it is necessary to identify the immediate causes which directly could cause this top event. Each of these causative events, in turn, is further broken down into subordinate events.

This process is continued until one arrives at basic input events that cannot be broken down further, or for which probability data are available so there is no need to go further. This process creates a diagram which resembles a tree whose branches extend and spread out downward, with each branch terminating in basic input events.

Figure A2 illustrates the diagrammatic arrangement of a fault tree, and Figure A3 identifies the goemetric symbolism that is commonly used in fault tree construction. It is to be noted that a fault tree consists of three essential elements -- input events, logic gates, and output events. The basic logic gates are of two kinds, namely OR gates and AND gates. If an output event can be caused by one or more input events, either when each acts by itself, or when they act together, these input events pass through an OR gate. On the other hand, if an output event can be caused only when all input events must act in combination, these input events pass through an AND gate.

This concept is illustrated in Figure A4 where the top event is defined as the lighting of the light bulb. For the circuit diagram which shows all the switches arranged in series, all four must be closed for the light to stay lit. In the logic diagram for this arrangement, these three switches are shown connected to an AND gate. In the other circuit diagram, where the four switches are arranged in parallel, it is evident that the closing of any one switch would be sufficient to light the bulb. The logic diagram for this case shows the four input events to pass through an OR gate. If the probability for each of the switches A, B, C, and D remaining closed were known, it would be possible to determine the probability of the bulb remaining lit for each circuit. That is, the symbolic logic relationships can be converted to algegraic expressions for numerical calculation.

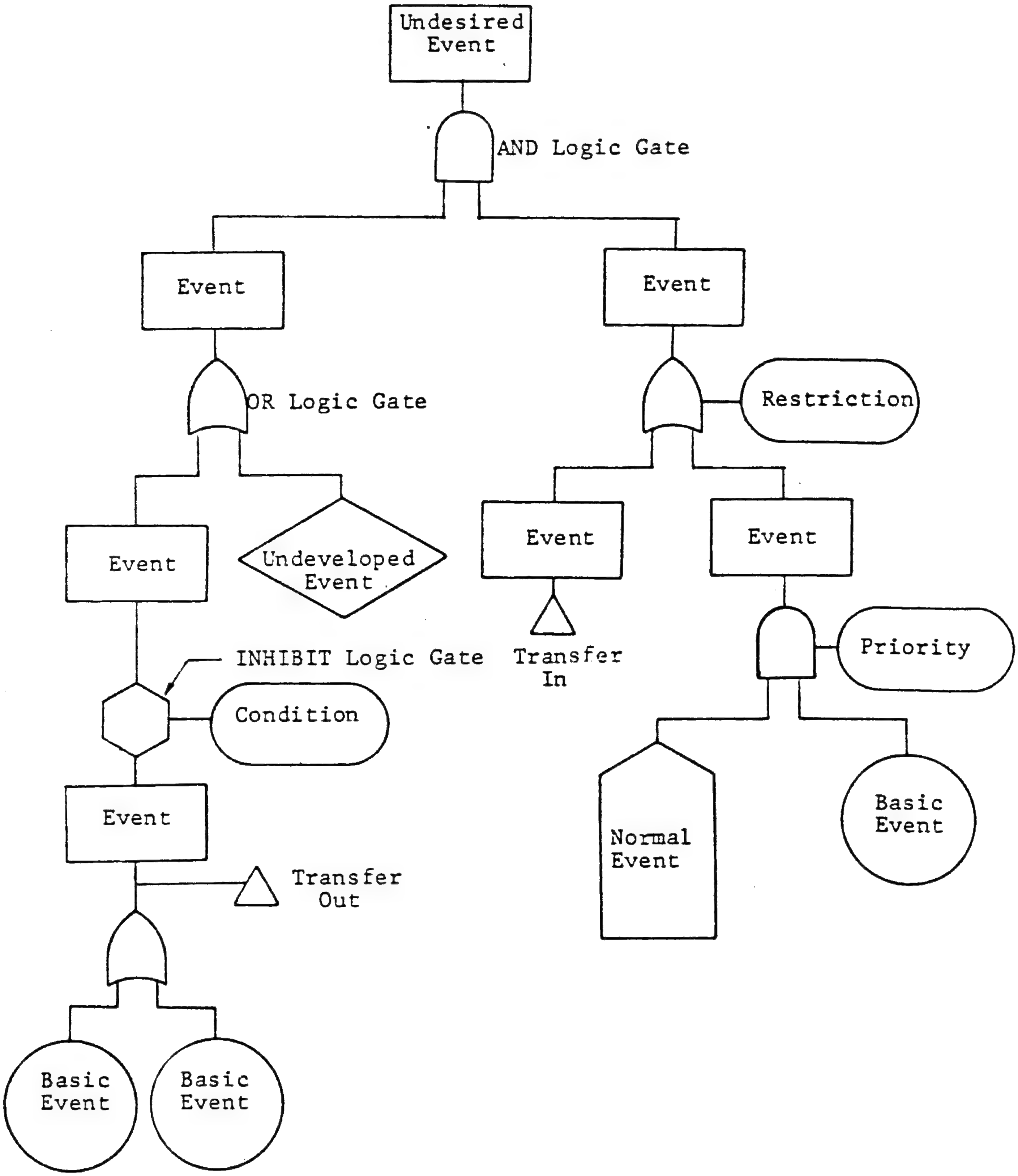
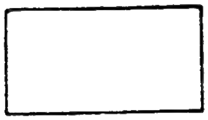
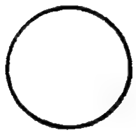


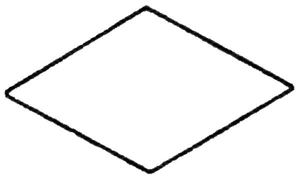
Figure A2 Diagramatic Arrangement of Fault Tree



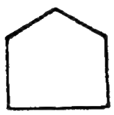
An event caused by one or more other events which are identified



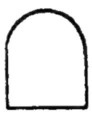
A basic input event that does not require further development as to causes



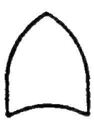
An event which is not developed further as to its causes because of lack of information or significance



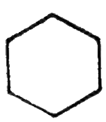
An event which is normal for the system; not a fault or failure per se



AND gate - output event occurs only if all the input events are present



OR gate - output event occurs when one or more of the input events are present



INHIBIT gate - output event is caused by input event only if specified condition is satisfied

Attached to logic gate to specify a condition

Continuation symbol to identical portion of fault tree

 Transfer In

 Transfer Out

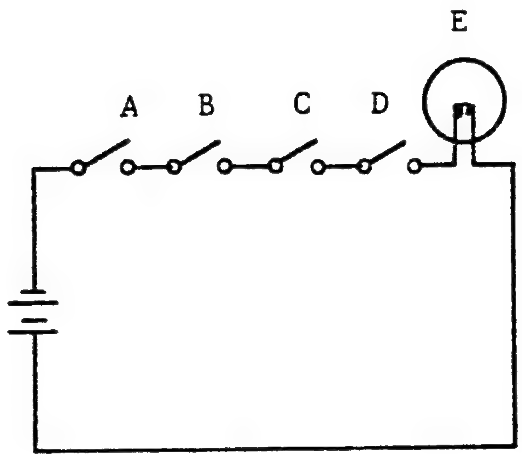
Continuation symbol to similar (but not identical) portion of fault tree

 Transfer In

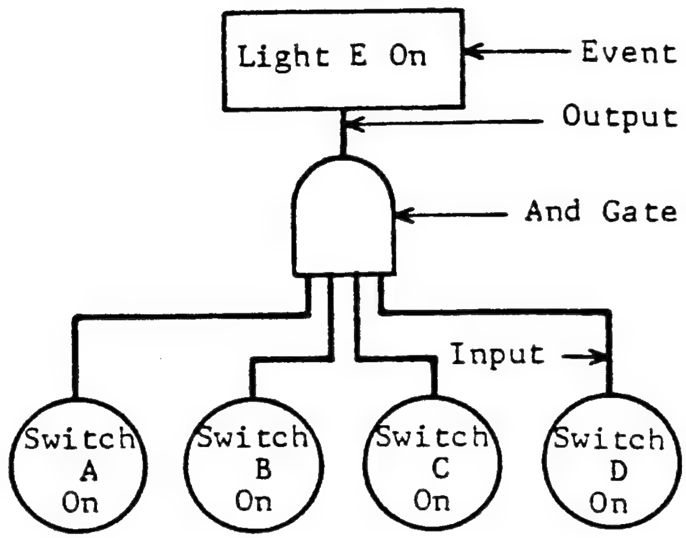
 Transfer Out

Figure A3 Symbols Used in Fault Tree Construction

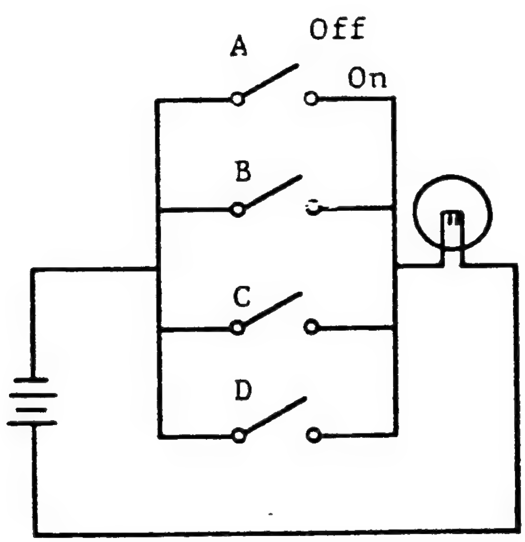
Circuit Analogy



And Gate Logic



Circuit Analogy



Or Gate Logic

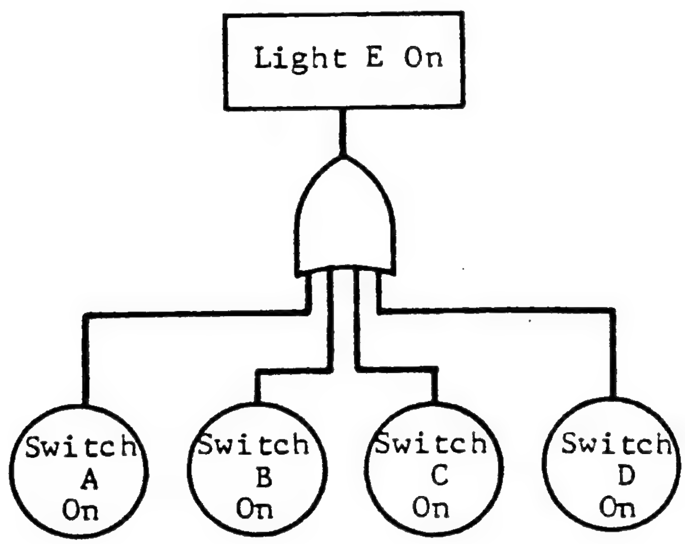


Figure A4 EXAMPLES OF USE OF AND AND OR GATES

A.3 QUANTIFICATION

IITRI has a fault tree analysis computer program for evaluating the fault tree diagrams. The first portion of the computer code uses a matrix approach known as the Boolean Indicated Cut Set (BIC) method to reduce the tree logic to a list of scenarios (cut sets) that "lead to" the undesired top event of the tree. These cut sets are the hazard scenarios that must be evaluated.

Each basic event on the fault tree must be provided a probability of occurrence or a failure frequency (with associated downtime) for quantification of the tree. Four types of data had to be compiled to quantify the trees:

1. System Scheduling Data
2. Part Reliabilities
3. Human Error Probabilities
4. Initiation Probabilities

Scheduling information was largely inferred from the Batelle Report (reference 2). Part reliability data has been compiled at IITRI during prior hazards and reliability analyses from numerous sources. The primary source of reliability data used, however, was a compilation of non-electronic parts data developed by the Reliability Analysis Center, an IITRI organization in Rome, New York (reference 1). Human error data has been compiled under a recent project conducted by IITRI for the Chicago Transit Authority (reference 6) and that was the primary source for for human error probabilities used. For initiation probabilities, the primary source of data was the Hercules Hazards Analyses for WADF presented in the Batelle report (reference 2). The most sensitive material for which data was available was used for each stimulus type. HBX-1 data was adopted for the majority of cases studied. In addition, there were numerous cases where data was unavailable and subjective judgements had to be used. For example, the probability that a significant amount of explosive would remain is a vessel during maintenance operations or that a local initiation would propagate into the bulk of material present were not easily quantified. Therefore, subjective judgements had to be used to establish probability values for the analysis.

The criteria for safety adequacy is stated in the contract as:

"The minimum acceptable level of risk for the operation and maintenance for the entire WADF complex and any subsystem is 97.5 percent probability with a 95 percent confidence level that a category 1 or 2* accident will not happen during 25 years of operation (40 hours per week)."

This translates to specifying that the hazard incident probability per year for the entire facility is less than or equal to 1/1000 with a 95 percent confidence level. The 95 percent confidence level criteria will be evaluated for the facility as a whole using the dominant cut sets derived for the different plant sections as the basis. Once the dominant cut sets for the facility as a whole have been identified using average failure frequencies and error probability values, Monte Carlo simulations will be run (on these dominant cut sets) to develop a distribution of failure frequencies for the WADF as a whole. The distribution created for the WADF will reflect uncertainties involved in predicting basic event frequency or probability values, for example due to variations in equipment, training of personnel, scheduling, etc. The 95 percent confidence level will then be determined using the derived distribution. These "total facility" results will be presented in the final report. For the mean time, a probability criteria of 1/10,000 will be used as a cutoff value instead of "1/1,000 with a 95 percent confidence level" in order to interpret the fault tree analysis results for each plant area.

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* Hazard categories are defined as follows:

Category 1 - Catastrophic. May cause death or system loss. System loss shall be defined as damage which results in the loss of 25 percent or more production capability and requires 30 days or more to repair.

Category 2 - Critical. May cause severe injury, severe occupational illness or major system damage. Major system damage shall be defined as that which results in more than 10 percent loss of production capability and requires more than 3 days to repair.

Category 3 - Marginal. May cause minor injury, occupational illness or minor system damage. Minor system damage shall be defined as that which results in 10 percent or less loss of production capability or requires 3 days or less to repair.

Category 4 - Negligible. Will not result in injury, occupational illness or system damage.

APPENDIX B

ETHER VAPOR PROBLEM

The amount of ether left in the propellant cannot be specified simply. The amount to be expected within the vapor space of a closed container however is related to its recent thermal history. Exposure to high temperature would drive alcohol and ether from the propellant into the cartridge case atmosphere until the temperature-vapor pressure equilibrium is attained. Cooling would reverse the process,driving the vapors back into the propellant, except that the rate would probably be orders of magnitude slower.

The explosive limits of diethyl ether and ethyl alcohol are given below along with their auto ignition temperatures.

	Explosive Limits (Vol. %) in Air		Auto Ignition Temperature, C
	Lower	Upper	
Ethanol	3.3	19	365
Diethyl Ether	1.9	36	160

This serves to point out that ether-air mixtures are more hazardous than alcohol-air due to a wider range of flammable mixtures and a substantially lower auto-ignition temperature. "In general, ethers are readily ignited by hot surfaces. These combustibles usually have a lower ignition temperature in air and in oxygen than do the corresponding paraffins and alcohols ... since ethers tend to form peroxides under a variety of conditions, they may appear to be unstable at room temperature."(ref. 5).

The explosives limit of an ether alcohol vapor mixture would lie between the limits given above. The exact value would depend on the mole fraction of each component in the vapor space.

The concentration of solvent vapors in the void spaces in a cartridge case prior to opening the case has been evaluated using four approaches to help to better understand the severity of this hazard:

1. Since ether vapors many times can be smelled upon opening packaged propellant, what is the minimum perceptible centration of the ether and how does this compare to the lower flammable limit (LFL)?

2. If the solvent remains in liquid form in the grains, how does its vapor pressure compare to the LFL?

3. If all the residual solvent in the propellant were mixed with air in the void space, what would the solvent vapor concentration be?

4. If the solvent is in solution with the propellant (i.e. not like a separated liquid) and if the solvent partial pressure is proportional to its mole fraction, what would the vapor concentration be?

By considering the minimum perceptible concentration of the diethyl ether (which can be smelled) it is found that a concentration of 0.7 ppm is required (ref. 7). This means that at least 0.7 ppm or a volume percent of 7×10^{-5} is present. This concentration level is well below the LFL of 1.9 percent for diethyl ether,therefore, the vapor may or may not be flammable based on this information.

If the solvent remains in the liquid form in the propellant (a very conservative point of view), the vapor in the void spaces must be in equilibrium with the liquid vapor pressure, i.e. at 40 mmHg for ethanol and 400 mmHg for diethylether. Thus, the ethanol concentration would at worst be (40 mmHg/ 760 mmHg) X 100% = 5.2% and similarly the ether concentration would be 52 percent, both well above the LFL. This shows that it is possible that the vapor could be concentrated enough to pose a hazard.

The third approach addresses whether there is enough solvent in the propellant to form a flammable mixture if it were all released from the propellant into the void spaces. The total mass of solvent m_s is given by

$$m_s = \rho \gamma \phi_s V$$

where ρ is the propellant mass density, γ is the fraction of the total volume that is occupied by the propellant (packing density), ϕ_s is the mass fraction of the propellant that is solvent and V is the total volume of the cartridge case. The mass of the gas in the void spaces between grains in the cartridge case is given approximately by:

$$m_g \simeq \rho a V (1-\gamma)$$

where ρa is the density of air. In this case it is assumed that the gas phase is primarily air, which is expected to be the actual situation. Then, the ratio of the solvent volume to the gas volume is given by

$$\frac{V_s}{V_g} = \frac{\left(\frac{m_s}{\overline{M}_s}\right)}{\left(\frac{m_g}{\overline{M}_g}\right)} \simeq \frac{\rho \gamma \phi s \overline{M} g}{\rho a (1-\gamma)} (\overline{M}_s)$$

in which $\overline{M}$ represents the respective molecular weights of solvent and total gas phase. This relation is derived directly from perfect gas law considerations.

Typical input values for this equation are

$$\rho = 0.0765 \text{ lb/ft}^3$$
$$\rho p = 100 \text{ lb/ft}^3$$
$$\gamma = 0.7$$
$$\phi_s = 0.03$$
$$\overline{M}g = 29$$
$$\overline{M}_s = 47$$

These values correspond to a V_s/V_g of 56 indicating that there is enough solvent to totally fill the void spaces in the gas phase. The same result is obtained if solvent properties replace the air properties in the equation.

The fourth approach is to scale the partial pressure of the solvent based on its mole fraction in the mixture with the propellant. This approach is valid for a mixture of liquids, but is really not appropriate for mixtures with solid materials. The result, however, is expected to be representative of what will happen in the real material. This approach predicts that the ether will be at about 8.4% and the alcohol at 1.7% by volume.

Other calculations could also be made. For example, the reduction in solvent partial pressure can be estimated by considering the solubility of the propellant in the solvent mixture. However, each approach has significant uncertainties. For this reason, it is strongly recommended that gas samples be extracted from actual cartridge cases to determine the flammability of the mixture with certainty.

From the available information, one must expect the vapor composition to be principally ether at room temperature; probably above the upper explosive limit (36% vol). Once the cartridge case is opened and the ventilating process takes place, the concentration must pass through the flammable range, i.e., from 36 to 1.9%. It is during this time that the greatest hazard is present, i.e., from thermal ignition due to the low auto ignition temperature or from ignition by spark. It should be noted that the minimum ignition energy for diethyl ether is 0.19 mj. An ungrounded person is capable of discharging on

the order of 15 to 22 mj. While good engineering practices and controls, principally in the form of ventilation can act to minimize the risk, it must be recognized that at some point a flammable, easily ignited vapor composition may exist.

APPENDIX C

INITIATION PROBABILITIES FOR PROPELLANTS

APPENDIX C

Initiation Probabilities for Propellants

Probit initiation curves were not available for the propellant materials to be processed in the preparation building and accumulator, but threshold initiation level (TIL) data was available. Typical materials to be processed and their TIL values for impact, friction, and electrostatic discharge are listed below (ref. 4):

Typical Propellants	Threshold Initiation Level — Impact ($ft\text{-}lb/in^2$)	Friction (psi @ fps)	Electrostatic Discharge (joules)
M6 (ground 20 mesh), Dry	10.2	52,500 @ 8	$\boxed{0.2}$
M1MP f/105 mm, Dry, 15 mils nominal thickness	6.6	57,200 @ 8	1.26
Fines (88μ to 126μ)	8.0	66,000 @ 8	$\boxed{0.013}$
M10 flake, Dry, 14 mils	6.6	$\boxed{30,800 @ 8}$	≥ 5.0
M10 Granule, Dry	12.6	152,941 @ 8	≥ 5.0
M30 (T-36), Dry	$\boxed{5.0}$	66,500 @ 8	≥ 5.0
M17, Dry	8.0	39,000 @ 8	≥ 5.0

The lowest TIL value for each type of initiation stimulus is highlighted. Two values are shown for ESD, both of which are for propellant fines or dust. Propellant granules are much less sensitive to ESD than the fines. In order to conduct a quantitative analysis, probit sensitivity curves were constructed using the TIL stimulus level at the 0.05 probability point and using a typical curve slope based on the probit curves for explosives presented in reference 2. The probit curves constructed in this manner are given in figures C-1 to C-3.

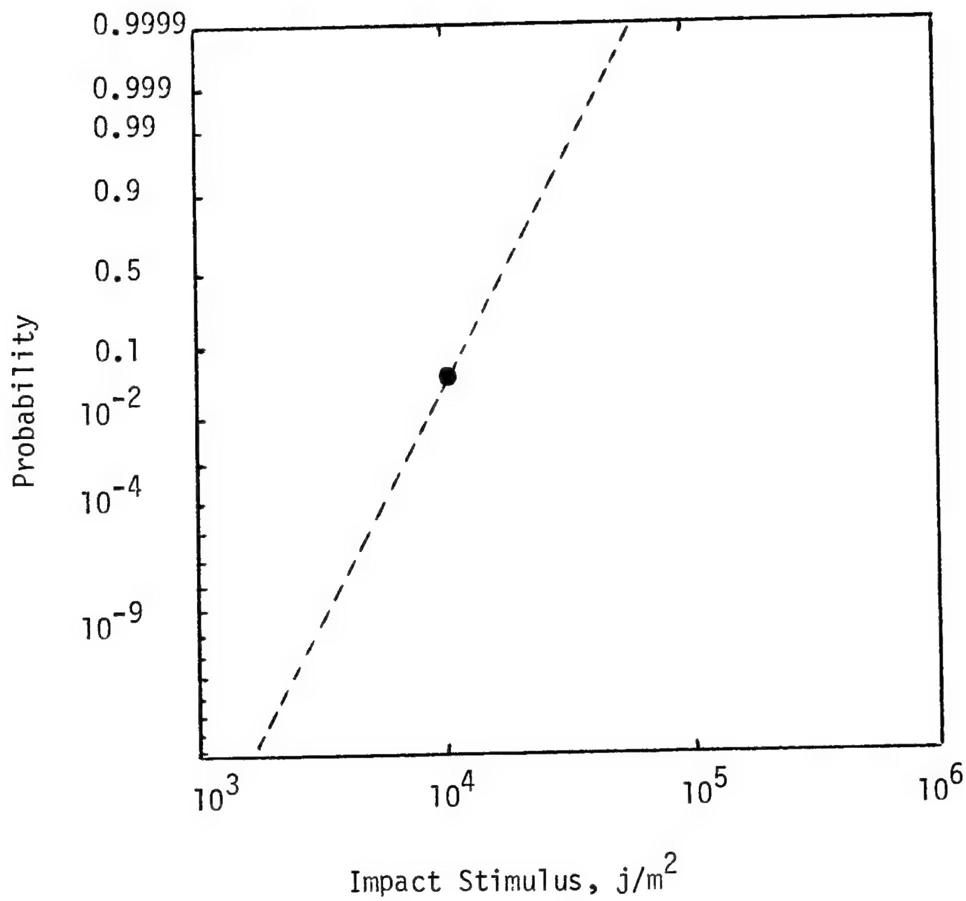

Figure C-1, Impact Probability Curve

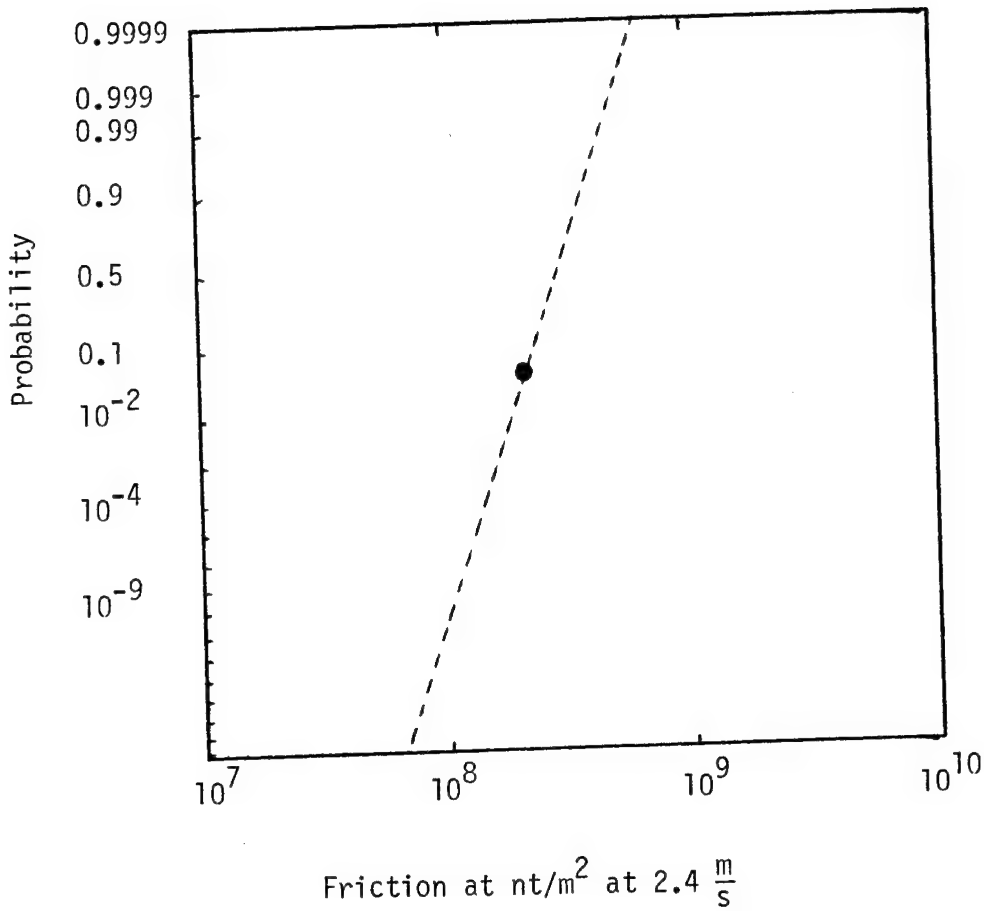

Figure C-2, Friction Probability Curve

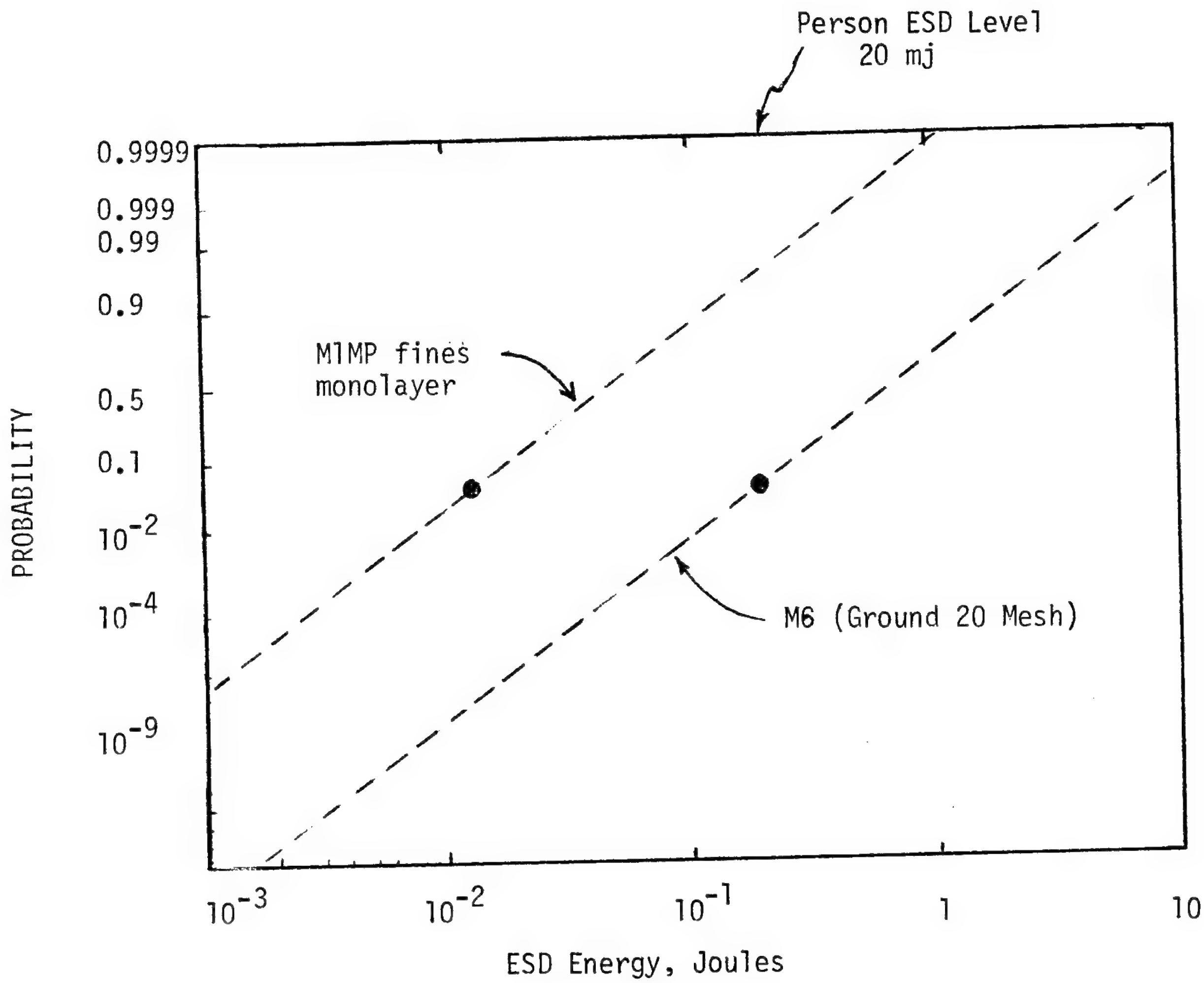

Figure C-3, ESD Probability Curves

APPENDIX D

TRANSIENT HEATING OF ITEMS DUE TO FRICTION

APPENDIX D

Transient Heating of Items Due to Friction

Several scenarios in the Preparation Building, Accumulator Building, Mechanical Removal Building and Large Cells involved situations with frictional heating of an explosive item such as a projectile, mortar shell, conveyor roller bearings, etc. Two simple models were developed to calculate transient heating during frictional operations. This was necessary for the calculation of the probability of an unwanted frictional operation continuing to the point of thermal initiation. These models are briefly described as follows:

Uniform Temperature Rise Model

This first model is used for those cases where small metal items are heated, and that temperature rise is assumed uniform throughout the item. The following expression specifies the time at which the item has reached a critical temperature capable of initiating an adjacent explosive.

$$t = \frac{mC_p}{hA} \ln \left[1 - \frac{hA}{Q} (T_c - T_o) \right]$$

where

M = item mass (lb)

Cp = item specific heat (Btu/lb-°F)

h = free convection heating coefficient (Btu/min-°F-ft^2)

A = item surface area (ft^2)

Q = heat input of item due to friction (See Appendix dealing with friction) (Btu/min)

T_c = critical temperature where adjacent explosive may initiate (°F)

T_o = ambient temperature (°F)

Scenarios analyzed with this method include frictional heating of mortar shell fuzes by the defuzing chuck (preparation building - Cell 3) and frictional heating of medium projectile nose fuzer by defuzing chuck (preparation building - Cell 6). In addition, frictional heating of the lower end and gravity takeup rollers of the smokeless powder conveyor (for stuck roller scenarios) could be evaluated in part using this approach.

Fin Temperature Rise Model

Several scenarios demanded a model for which one can calculate temperature at any position along a fin, at any point in time, where a constant frictional heat source is present at the fin's origin. For these cases the following expression was derived.

$$T_X = T_o - \frac{\mu \cosh \alpha\,(L-X)}{\alpha \sinh \alpha L} + \frac{\mu}{L}\, e^{-\nu t}\left[\frac{1}{\alpha^2} + 2\sum_{4=1}^{\infty} \frac{1}{\frac{n^2\pi^2}{L^2} + \alpha^2} \times \cos\left(\frac{n\pi x}{L}\right) e^{-K\frac{n^2\pi^2 t}{L^2}}\right]$$

where

t = time (min)

T_X = temperature at distance X along fin (F)

T_o = initial temperature of fin (F)

L = length of fin (ft)

X = distance from origin along fin (ft)

$\mu = -q/h$ $\quad$ q = friction heat flux per unit cross-sectional area of the fin (Btu/min-ft^2) applied at X = 0

κ = thermal conductivity of the fin (Btu/min-ft-F)

$\alpha^2 = \frac{\nu}{\kappa} = \frac{hp}{\kappa A}$ $\quad$ h = free convective heating coefficient (Btu/min -°F-ft^2)

p = fin perimeter (ft)

A = cross-sectional fin area (ft^2)

$\nu = \frac{hp}{\rho CA}$ $\quad$ ρ = fin density (lb/ft)

c = fin specific heat (Btu/lb-F)

$\kappa = \frac{k}{\rho C}$

Scenarios were analyzed with this expression to determine if a critical initiation temperature can be reached, and if so, how long it takes. Some of these scenarios studied include:

- motor shell center clamp frictional heating (preparation building - Cell 3)

- large projectile frictional heating against vertical defuzer clamp (Large Cell C)
- conveyor roller bearing overheating
- conveyor stuck roller scenarios
- etc.

APPENDIX E

ELECTROSTATIC DISCHARGE ASSOCIATED WITH DIELECTRIC SURFACES

APPENDIX E

Electrostatic Discharge Associated With Dielectric Surfaces

Dielectric surfaces may store considerable charge, but because of their low conductivity only a small portion of the charge will drain out upon discharge. Therefore, the method used for evaluating dielectric surfaces emphasizes the local sparking phenomenon rather than the total stored energy. Consider a grounded sphere of radius R, and distance H above a charge wall (see Figure E1).

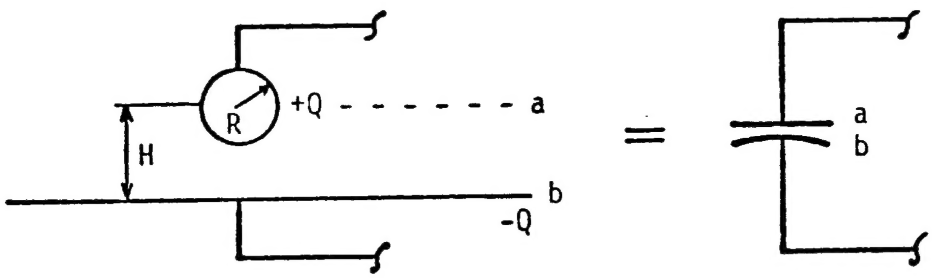

Figure E1

The capacitance of a charged sphere above a grounded wall can be determined from mirror image analysis to be

$$C = 2\pi\varepsilon_m R \; \frac{2H-R}{H-R}$$

Since the capacitance of any electrical component is purely a function of geometry, this capacitance expression applies also to the case of inverse charging, with which we are concerned (charged wall and grounded sphere). Discharge will occur when the sphere is close enough to the wall to produce the breakdown electric field in sufficient volume between the sphere and the wall. We assume that this occurs when the sphere is height H above the wall. At that instant, the voltage is approximately

$$V \approx E_B H$$

The energy released in the spark is computed from

$$W = \frac{1}{2} CV^2$$

Inserting C and V given above into the energy equation we obtain:

$$W = \pi\varepsilon_o \, R \left(\frac{2H-R}{H-R}\right) E_B^{\,2} \, H^2$$

For this energy to be maximum with distance from the wall $\partial W/\partial H = 0$. Doing this differentiation a quadratic equation results with the following solutions for H.

$$H = \begin{cases} 1.39R \\ 0.36R \end{cases}$$

The second value is impossible since the sphere would have to have penetrated the wall at that point. This leaves H = 1.39R as the only realistic solution. Using H = 1.39R in the expression derived for energy we obtain

$$W_{max} = 8.82\pi\varepsilon_o R^3 E_b^{\,2}$$

In analyses of dielectric surfaces, breakdown was assumed to occur and the energy at breakdown was computed using this equation.

LIST OF SYMBOLS

A = item surface area (ft^2)

A = cross-sectional fin area (ft^2)

C = capacitance (farads)

c = fin specific heat (Btu/lb-F)

Cp = item specific heat (Btu/lb-°F)

E_B = breakdown electric field strength (volts/meter)

H = height of equivalent grounded sphere above wall for ESD capacitance estimates (meters)

h = free convection heating coefficient (Btu/min-°F-ft^2)

L = length of fin (ft)

M = item mass (lb)

M_g = mass of the gas in the void spaces between grains in the cartridge case

$\overline{M}$ = respective molecular weights of solvent and total gas phase

m_s = the total mass of solvent

p = fin perimeter (ft)

Q = heat input of item due to friction (Btu/min)

q = friction heat flux per unit cross-sectional area of the fin (Btu/min-ft^2) applied at $X = 0$

R = radius (meters)

t = time (min)

T_x = temperature at distance X along fin (F)

T_o = initial temperature of fin or ambient temperature (F)

T_c = critical temperature where adjacent explosive may initiated (°F)

V = the total volume of the cartridge case

v = voltage (volts)

V_s/V_g = ratio of the solvent volume to the gas volume

W = energy (joules)

X = distance from origin along fin (ft)

α = fraction of the total volume that is occupied by the propellant packing density)

ε_m = permittivity of the medium

Φ_s = mass fraction of the propellant that is solvent

κ = thermal conductivity of the fin (Btu/min-ft-F)

ρ = fin density (lb/ft)

ρ = propellant mass density

ρ_a = density of air